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RESEARCH TRIANGLE INSTITUTE
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FINAL REPORT: VOLUME II

R-OU-82/83

Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs

Philip McMullan, John Neblett, Edward Hill,
Hale Sweeny, Philip McGill, and Rodney Sink

January 13, 1964

Prepared for
Office of Civil Defense
United States Department of Defense

under

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Sub-tasks 4613A & 4521A

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by

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ABSTRACT FOR VOLUME II

This volume contains five studies concerned with obtaining, compiling, or analyzing fallout shelter protection data. These studies cover the following subjects: (1) a review of the residential basement data which were obtained from the 1960 U. S. Census of Housing; (2) an examination of electric power availability in the postattack period, with emphasis upon fallout protection in power plants; (3) the preparation of a procedure for extracting summary distributions of overpressure, reference intensity, and fallout arrival time and relating these to numbers of people exposed; these data are to be extracted from the Attack Environment III output tapes of the Jumbo III damage assessment system; (4) the re-evaluation, with National Fallout Shelter Survey data, of an analytical model for predicting fallout protection for people as a function of their distance from the center of a city; and (5) a statistical analysis of NFSS data from Houston, Texas; and Durham, North Carolina, performed to determine distribution functions expressing their shelter characteristics. These analytical representations of NFSS data are applied, in an illustrative example, to optimal allocation of improvement dollars to ventilating below ground shelters to increase their capacity.

CONTENTS

Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs: Volume II

I. INTRODUCTION

This volume reports five studies performed under Office of Civil Defense sub-tasks 4613A, Improvement of Protection Data Base for Damage Assessment, and 4621A, Data Base on Shelter Needs. All are concerned with supplementing, evaluating, or employing the data from the National Fallout Shelter Survey (NFSS). These studies have contributed to the two major investigations reported in Volume I of this final report (Reference a) and would normally have appeared as appendices to Volume I. They have been bound separately to keep Volume I to a convenient size.

Volume III (Reference b) reports an investigation of the physical vulnerability (PV) data in the NFSS. It is bound separately because of the CONFIDENTIAL casualty and fatality curves which are included.

The paragraphs below summarize the five studies reported in the present volume.

II. THE BUREAU OF THE CENSUS RESIDENTIAL BASEMENT DATA

The purpose of this study was to investigate the availability of Bureau of the Census residential basement data and its compatibility with the Phase 1 findings of the National Fallout Shelter Survey.

After considering the nature of the data and pointing out some cautions in its use, the conclusion is reached that the census data could be combined and used with the NFSS in fallout casualty computation programs.

A brief section on some possible additional uses of the information in crash CD studies and local shelter planning follows the main sections; two annexes provide population, shelter space, and basement figures for 180 tracted metropolitan areas.

III. ELECTRIC POWER AVAILABILITY IN THE POSTATTACK PERIOD

This sub-task was performed jointly for the Directorate of Research and the Shelter Survey Division. Its objective was to design a form for a mail questionnaire to identify the blast and fallout resistance in electric power generating stations and substations. It was demonstrated that reliable estimates of fallout protection and systems vulnerability data to the required significant detail could not be collected using such a questionnaire. As a pilot study, an analysis of the vulnerability of power generating stations and transmission systems to nuclear attack was made for the Duke Power Company system.

IV. A MODEL OF POPULATION DISTRIBUTION IN SHELTER

This sub-task extended work previously performed by Mr. Jack Rogers of SRI in which a mathematical model was used to indicate the distribution of people in shelter throughout a city (Reference c). The Rogers model was completed prior to the NFSS, using shelter data obtained in preliminary studies of selected state capitals. The RTI sub-task re-evaluated and modified the original model in an attempt (only partially successful) to fit the NFSS data. The model was not further developed for systems evaluation because it models a static situation rather than the dynamic movement to shelter later found to be more relevant.

V. SUMMARIES OF ATTACK ENVIRONMENT DATA

This sub-task was performed at the request of the project monitor to assist an Office of Civil Defense in-house project whose objective was to design procedures for national CD systems evaluations. The sub-task suggested a procedure by which large area statistical summaries of attack environment data may be obtained from the Jumbo III system by using a three dimensional sort summary routine.

VI. DISTRIBUTION OF SHELTER CHARACTERISTICS

This sub-task described a method for reducing the NFSS data to a more compact and useful form by expressing it by statistical distribution functions. As an example of potential applications, the data for Durham, North Carolina and Houston, Texas, is used in determining optimal allocations of funds to ventilate below ground shelter spaces to increase their capacity.

VII. REFERENCES

a. Philip McMullan et al. Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs. Volume I (UNCLASSIFIED). (Final Report on OCD Sub-tasks 4613A and 4521A), Durham: Research Triangle Institute, Operations Research Division, 13 January 1964.

b. Philip McMullan et al. Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs. Volume III (CONFIDENTIAL). (Final Report on OCD Sub-tasks 4613A and 4521A), Durham: Research Triangle Institute, Operations Research Division, 20 January 1964.

c. Jack Rogers. A Theoretical Study of Existing Fallout Shelters. Menlo Park, California: Stanford Research Institute, March 1962.

Appendix A

An Examination of Bureau of the Census Residential Basement Data

This Appendix was originally submitted to OCD as Research Memorandum RM-82-9,* except for minor editorial changes.

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* Philip B. McGill. An Examination of Bureau of Census Residential Basement Data. Research Memorandum RM-82-9. Durham, North Carolina: Research Triangle Institute, Operations Research Division, 10 May 1963.

Appendix A

An Examination of Bureau of the Census Residential Basement Data

I. INTRODUCTION

This paper is a report of work carried out as part of OCD projects 4613A and 4521A. Research has been conducted on the development of procedures for the extraction of data on the location, capacity, and protective characteristics of fallout shelters and the integration of these data, when appropriate, into the damage assessment programs of the National Resource Evaluation Center. Related research memoranda have discussed our efforts to use the data from the National Fallout Shelter Survey. There are times and areas where it is impossible to shelter the entire population of an area in the spaces enumerated in the shelter survey. These excess persons will have to be sheltered elsewhere; possibly in residential basements and houses. It is therefore valuable to analyze the presently available data on residential basements and to determine if it can also be integrated into the damage assessment routines. Such is the purpose of this paper.

A. General Conclusions

1. Data on residential basements were collected in the course of the 1960 Census of Population and Housing. These data are a valuable adjunct to the National Fallout Shelter Survey, for they concern structures that, in the main, have too low a protection value to have been considered in the NFSS and yet have more protection than houses.

2. Basement data were published only for 180 tracted areas, (Reference A-a) but the remainder is still stored, unpublished, at the Bureau of the Census. It would, therefore, be feasible to extract and edit basement data and combine them with the NFSS output for use in the NREC's Jumbo III system of casualty computation programs (Reference A-b).

3. There is some overlap between the 1960 Census basement data and the shelter survey data, occurring when the basements of apartment buildings had sufficient protective value to have been surveyed. It is likely that this will be only a small overlap, and this overlap will probably diminish when Category 1 shelters, as designated in the shelter survey, are disregarded.

4. The annexes to this report point out that the Jumbo III climatic assumptions (Reference A-b) could be greatly improved by using Census basement data, as extremes in basement distribution exist between cities even within a particular state.

5. Finally, the 1960 Census basement data should have application for, and interest to, civil defense officials, especially on the local level, and those persons interested in crash civil defense measures.

B. Content of the Present Memorandum

After the introduction, Section II of this appendix develops a background stressing the importance of basements in casualty assessment and includes a section on prior studies which have considered basement distribution.

Section III is concerned with the nature of Bureau of the Census basement data itself, and includes some cautions to be observed before using them, although it will be seen that no serious problems arise. Next, an example of the compatibility of the two data sources, Census and NFSS, is presented for a representative city, Birmingham, Alabama.

A further objective of the appendix is to consider the validity of the Jumbo III climatic assumptions concerning basement distribution. Toward this end, Annexes A-1 and A-2 are provided to show population, shelter space, and basement data for 180 tracted areas in the United States. It is hoped that these annexes may be of some general use and interest beyond the immediate scope of this report, especially since the 180 tracted areas contain approximately 92 percent of all NFSS Phase 1 shelter spaces and 95 percent of all spaces in categories 2-8.

Two remaining sections; some possible uses of basement data by (a) local CD planners and (b) those interested in crash civil defense measures and planning, along with a general summary, complete the paper.

II. BACKGROUND

A. Uneven Shelter Distribution

While the total number of fallout shelter spaces as estimated in Phase 1 of the NFSS exceeded the country's population, regionally there is uneven distribution. For example, Region 1 contained less than 20 percent of the national population, but over 40 percent of the total shelter space. With this region taken out of the national total, the remaining seven regions contain shelter for approximately 80 percent of their respective populations. In fact, only three regions exceeded their populations in terms of shelter space. The five remaining under-sheltered regions had a combined population of around 82 million, but a total of less than 50 million shelter spaces, or 60 percent of the needed amount. These percentages pertain to the total number of spaces, *i.e.*, categories 1 through 8. However, Category 1 accounted for over half (58%) of the total number of spaces, and if Category 1 were dropped there would be shelter space for only 65 percent of the population.

Regional statistics, as used here, serve to point out deficiencies in an aggregate sense. For the purposes of this report we are interested in data on a smaller scale such as standard locations (SL); but just as wide differences occur between regions, so are there extremes between SL's within a city. Birmingham, Alabama will be used later to illustrate this point.

B. Prior Studies

The idea of estimating that portion of the population which could reasonably be sheltered in residential basements is not new. The importance of basement shelter is illustrated in the document Shelter (Reference A-c), especially in the following statement: "A 1956 study made for FCDA showed that there was basement

space available in Wisconsin for 12 times the population of the State. In Milwaukee 15 percent of this space was in large buildings and 85 percent in houses. In the remainder of the State, the proportions were 5 percent and 95 percent."

Knowledge that at least in parts of the country there are numerous residential basements is one thing, accurate application remains another. Before the NFSS was completed, NREC population casualty assessments depended primarily upon gross estimates of population distribution in basement shelters. A pioneer study was made by Stanford Research Institute in June, 1956 (Reference A-d). Attempting to correlate basement distribution with severity of winters, this report projected three bands of states with light, moderate, and severe winters for both metropolitan and non-metropolitan areas. This assumption, combined with other assumed distribution patterns of shelter PF categories, was incorporated into the Jumbo III program. Thus, the validity of such basement assumptions materially affects casualty estimates and resource allocations resultant from such assessments.

A Rand Corporation Research Memorandum presented the percentage of population having ready access to dwelling basements by region, (Reference A-e) and a report from Technical Operations Incorporated listed the percentage of population with ready access to basements for states within each OCD region (Reference A-f).

However, prior to the 1960 Census of Population and Housing, accurate data had not been available by which to estimate residential basements on a smaller or lower level such as a county or standard location.

III. NATURE OF THE U. S. CENSUS BASEMENT DATA

As part of the 1960 Census of Population and Housing, a question concerning residential basements was asked of a 20 percent sample of housing units (Reference A-g).

The question was stated as follows:

	with a basement? 0
H 33. Is this house built:	on a concrete slab? 0
	in another way?. 0

Findings were tabulated and published for 180 tracted areas, of which all but two are Standard Metropolitan Statistical Areas (SMSA's). The 180 reports represent nearly 85 percent of the total number of SMSA's listed in 1960. Data for smaller towns and rural areas were collected although not published, and it is understood that NREC purchased the entire raw data tapes from the Bureau of the Census.

The Bureau of the Census defines living quarters in terms of either housing units or group quarters. Because the above basement question was asked of housing units but not of group quarters, the difference between the two must be understood. "A house, an apartment or other group of rooms, or a single room is regarded as a housing unit when it is occupied or intended for occupancy as separate living quarters, that is, when the occupants do not live and eat with any other persons in the structure and there is either (1) direct access from the outside or through a common hall or (2) a kitchen or cooking equipment for the exclusive use of the occupants of the unit." Those occupied quarters which do not qualify as housing units are classified as group quarters. They are located most frequently in institutions, hospitals, nurses' homes, rooming and boarding houses, military and other types of barracks, college dormitories, fraternity and sorority houses, convents and monasteries, etc. As a class, many of the structures described as group quarters by the Bureau of Census, were eligible to be surveyed by NFSS.

Just as group quarters did not show up in the 1960 Census basement data, single unit residences were not surveyed in the NFSS and therefore, the two classes basically complement each other.

A. Some Cautions in Using Basement Data

There is an area of possible overlap between Census data and NFSS which must be pointed out. This is in the category of multi-unit residential dwellings - mainly apartment buildings. Apartment buildings were surveyed both by the Bureau of the Census and by NFSS, and before using Census basement data in connection with NFSS, consideration must be given to the danger of double counting, or, counting the same basement twice.

Further cautions should also be pointed out at this point. Since the 1960 Census statistics on basements were presented in terms of the number of housing units in structures, and a statement on each questionnaire cautioned the respondent to answer the basement question in terms of the whole building rather than a particular apartment or housing unit, the final count multiplied an apartment basement by the number of dwelling units in that building. For example, if a 10 unit apartment building had a basement, then that basement would be counted not once, but 10 times. On the other hand, the enumeration of the NFSS was in terms of structures rather than housing units.

A third caution is that Bureau of the Census basement figures are in terms of all housing units, not just those that were occupied at the time of the count. At any given time there is the likelihood that some houses with basements would be unoccupied but this in itself does not exclude their possible use.

B. Comparison of Census Data with NFSS for Birmingham, Alabama

1. Method of Analysis

In order to check the comparability of the two data sources and also the degree of possible overlap or double counting, an analysis was made of Birmingham, Alabama, Phase 1 Survey Data. This was accomplished by means of the USE CLASS CODE which gives the classification or type of use of residential and commercial buildings. NUMBER ELEVEN of the code represented residential apartment buildings and hotels. In nearly every case the name of the facility stated whether the building was an apartment or a hotel.

Using this method to select out apartments, it was estimated that there were approximately 175 facilities in the apartment category within the city. Due to the particular design of individual buildings, a number of the 175 facilities had two and three parts totaling an additional 64 sections. Of the grand total (239 sections), protection factor information was given for 77 basements; that is, 77 basements were said to have had a PF of at least 20. For the remaining apartment buildings there was either a statement that the PF was less than 20 for each story or, that one or more floors had a PF of at least 20, but we can not tell whether there was a sub-20 basement or not. The survey estimated that the 77 basements listed could hold something less than 2,000 persons. Of course, floors above these basements might also hold people. Thus, there are 77 basements representing less than 2,000 potential spaces in which overlap with the 1960 Census data is possible.

The City of Birmingham, excluding Bessemer and the balance of Jefferson County. was divided into 61 standard locations, or two more SL's than Census tracts because two of the Census tracts were subdivided into two additional SL's. One standard location was omitted from the printout entirely, indicating that no buildings were surveyed in that SL. Only 15 SL's in the NFSS Phase 1 Data listed apartment buildings. Of these 15 SL's, 4 contributed 118 of the total of 175 apartment facilities, and 4 other SL's, had a total of only 6 apartment buildings among them. In other words, the majority of apartment buildings surveyed were located in relatively few standard locations in the city. At least for those standard locations without apartment buildings, there can be no overlap between Bureau of the Census and NFSS data.

2. Degree of Overlap of Data

How great is the magnitude of possible overlap for the city as a whole? Using the average population per household for Birmingham (3.3) multiplied by the number of Census enumerated basements in the city to determine potential basement spaces, we may conclude that residential basement shelter space is available for

roughly 106,580 persons. In these terms, the possible overlap would be less than two percent (2,000/106,580).

3. Need for Basements

Is there a need for residential basement shelter space in Birmingham? If not, there would be little point in concerning ourselves with accurate basement data (of course, the same question may be applied to any city or area). Phase 1 Data indicated there were more spaces, categories 1-8, in the city than there were people (417,464 vs. 335,887), however, over 50 percent of the total space was to be found in Category 1 (PF 20-39). With this category omitted, the total number of shelter spaces is reduced to 198,326. In other words, only 59 percent of the population could find shelter in categories 2-8. Of the reduced total of 198,326 spaces, almost 67 percent may be found in one standard location, over 80 percent in two, and 90 percent in but five SL's.

Even assuming complete freedom to move across standard locations within the city, once Category 1 has been dropped over 40 percent of the population must find shelter elsewhere - mainly in residential basements and even worse, houses. While it is not the purpose of this appendix to predict population reaction to nuclear attack, certain problems would arise under the assumption that the population could and would move across standard location boundaries seeking shelter. Such factors as amount of warning time, congestion, knowledge of shelter location, etc. would all likely play a role in shelter selection by individuals and family units. Without making further assumptions, the mere fact that the very large percentage of shelter spaces (categories 2-8) available in Birmingham are located in relatively few standard locations and that only 59 percent of the population could be sheltered in public shelters lends importance to the necessity of considering houses and especially basements as sources for additional shelter space; and from this it is important to have as accurate a picture of the basement situation as possible in order to plan civil defense measures more effectively and efficiently.

IV. U. S. CENSUS DATA AND JUMBO III

A. Climatic Assumption

A further objective of this appendix is to consider specifically the accuracy of the Jumbo III assumption concerning basement distribution for the three climatic regions. The issue raised here is whether presently available tables are accurate or not; or, can any such summary table, even if revised, be sufficiently sensitive in casualty predictions at less than regional summary levels? It is the view of this report that the answer is no.

To support this conclusion Annex A-1 presents a listing of 180 reports including 178 SMSA's and two New Jersey counties. For each city there is a population estimate based on the 1960 Census figures, a percent of the population that could be covered by the surveyed shelters in the NFSS Phase 1 finding for both categories 1-8 and 2-8, and finally, the percent of population that could find shelter in residential basements independent of surveyed shelters.

The column entitled "% of Pop. Assignable to Residential Basements" was derived by first taking the U. S. Census basement figure for the SMSA and multiplying by three, which is roughly the average number of persons per household. The resulting figure was then divided by the population figure for the SMSA to arrive at an estimate as to the percent of population which could be sheltered in basements independent of any public shelters. Such a figure taken by itself tacitly assumes that people will not move to another family's basement if they do not have one themselves.

B. Comparison

How do these results compare with the climatic assumption of Jumbo III? Under the Jumbo assumption seven states composing Region 3 are assumed to have 10 percent basement availability. An examination of the data for this region shows some rather extreme differences. For example, only one percent of the population of the Tampa-St. Petersburg, Florida SMSA could be placed in residential basements (allowing 3 persons per basement) while on the other hand, Winston-Salem, North

Carolina in the same region could accommodate 46 percent of its population in basements. As Category 1 is dropped, the basement takes on a new importance. If categories 1-8 are used, a city such as Atlanta, Georgia would have more than enough shelter space for the population. But once Category 1 is dropped, 20 percent of the population would need to seek other shelter including basements. If the Jumbo III assumption of 10 percent were used, we would have to say that 10 percent of the population would have to stay in houses when actually there is basement space for at least 35 percent of the city's population.

Chart I graphically points out the variability of residential basement availability among the 25 SMSA's listed for Region 3. The horizontal axis breaks down into classes the percent of population that could be assigned to residential basements, and the vertical axis represents the percent of population to be found within each class.

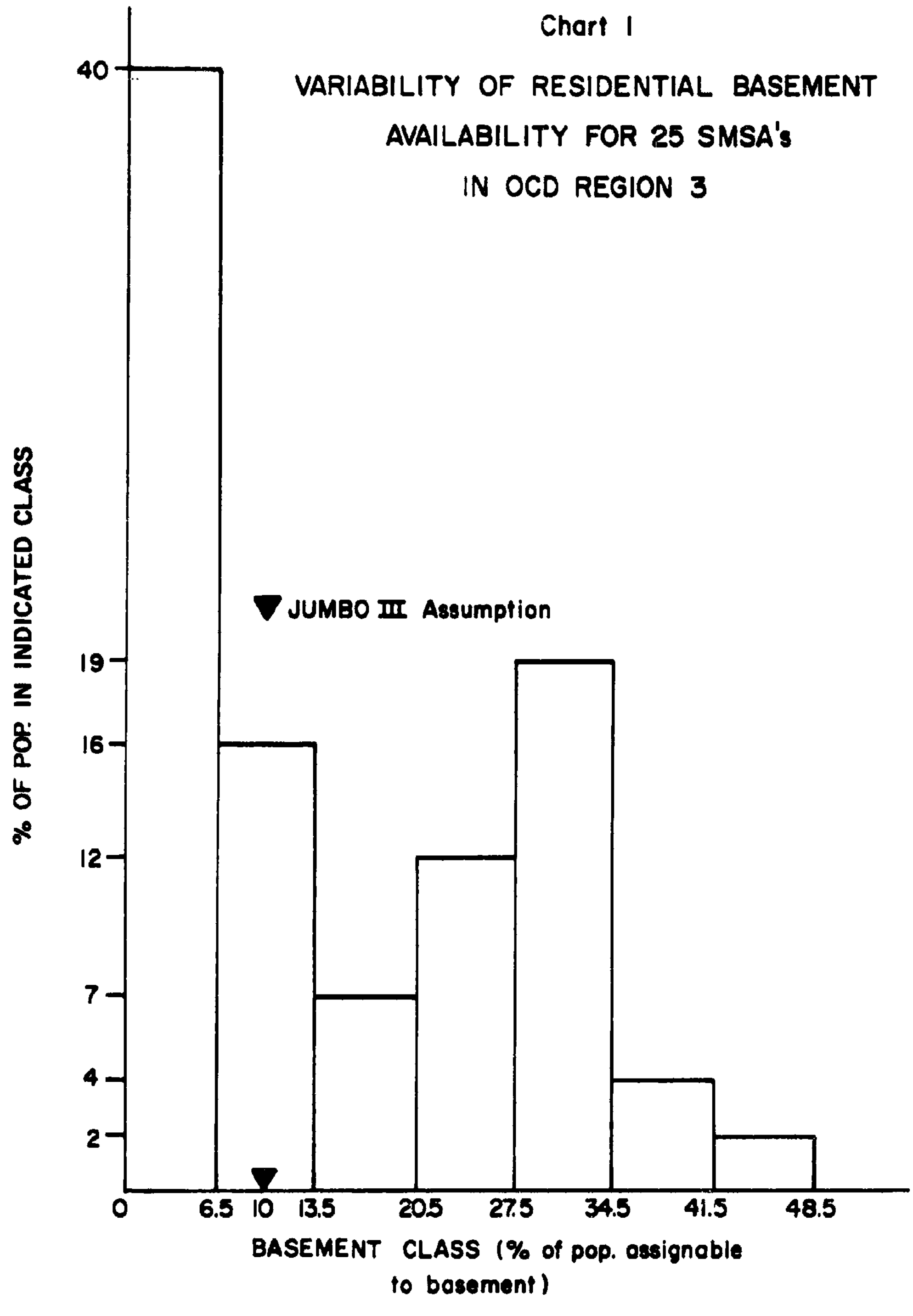
If the mean were estimated for the 25 listed cities, the average basement availability would be a little more than 15 percent. However, the chart indicates that 40 percent of the total population of the 25 SMSA's is to be found in cities that have 6 percent, or less, basement availability, and that at least 25 percent of the population is to be found in cities that have 28 percent, or better, basement availability.

Of the 25 SMSA's tabulated for Region 3, almost half (12) exceed the 10 percent basement figure, and there are only two cities, Durham, North Carolina and Nashville, Tennessee where dropping Category 1 does not make a significant difference.

On the other hand, a state such as Virginia is assumed to have 50 percent basement availability, yet in the metropolitan areas of Richmond, Norfolk-Portsmouth, and Newport News-Hampton, Virginia the figures are 29, 10, and 7 respectively. In these cases the Jumbo III assumption overestimates the number of basements available.

Chart I

VARIABILITY OF RESIDENTIAL BASEMENT AVAILABILITY FOR 25 SMSA's IN OCD REGION 3



Discrepancies may be found in other regions as well. Ohio is listed as an 80 percent basement state, but there are three SMSA's that are in the 60's. Nevada, a 50 percent state, had over 40 percent of its population living in Las Vegas, which in turn could shelter only three percent of its population in residential basements. In California, a 10 percent state, the percentage of population assignable to residential basements ranges from 1 percent in the Los Angeles-Long Beach area to 24 percent in Stockton. In Annex A-1, 10 cities are listed under California and in only one case, San Francisco-Oakland, would omitting Category 1 fail to make an important difference.

These have been a few examples to stress the point that even within a state there are some rather wide differences and that to the degree data on a standard location basis can be obtained and incorporated, it would tend to make the output of the Jumbo Program that much better and more accurate.

C. Integration of Data Into Jumbo III

The remaining question to be answered is whether the residential basement data can be incorporated into such a program as Jumbo III. In the RTI computer program entitled, A Program to Integrate National Fallout Shelter Survey Data Into Jumbo III Casualty Computations, and described in Chapter 2, Volume I of this final report, provision was made to leave a space in the input record to the computation of the shelter distribution factor for data on residential basements. A position in the factor itself is designated to represent that portion of the population which could be sheltered in basements. This latter shelter level is now filled in the computer program by the use of a regional average keyed to the physical vulnerability code.

Basement shelter information is available as a result of the 1960 Census of Population and Housing. It would, therefore, be possible to have these data compiled and inserted into the shelter survey data records. As was said above, space for this information was left in these records with the thought that such a course of action might prove useful and desirable. This would require a great deal of clerical effort to gather the data, get it into the same sequence as the standard

locations identified on the input tape, and inserted into the proper position in the records. It is possible to do, however, and it might be a valuable addition to this data record, well worth the effort required to achieve this end.

V. USES OF THE U. S. CENSUS BASEMENT DATA

A. By Local CD Planners

While the main purpose of this appendix is to consider basement data in relation to national damage assessment programs such as Jumbo III, the U. S. Census basement data may be of significant use to local Civil Defense officials, especially in those cities and areas that form Standard Metropolitan Statistical Areas. SMSA published reports usually contain a map of the Census tracts for the central city and adjacent area. From such a report, a local CD director could receive a clearer picture of the basement and housing situation in each of the pertinent tracts and his area as a whole.

For those areas too small to be classified as an SMSA, photocopies of tabulated but unpublished data from the 1960 Census can be provided at cost. Additionally, the basement question was asked on the questionnaire for city blocks (cities of 50,000 or more inhabitants and some other cities which had specifically contracted for data to be published by block); although the results were not published in the city block reports, it is assumed that these data would be available at cost and could pinpoint more exactly the location of basements in a given city. This information should be most helpful in those locations where the NFSS indicated there was an insufficiency of shelter spaces in the survey.

B. In Crash CD Planning

Special mention should be made of the use of basement data in connection with crash civil defense measures. In those cases or situations where it would be up to the individual or family unit to make a contribution toward shelter protection improvement, the residential basement remains a logical choice when available.

Many basements could within a relatively short time period be improved so as to offer a fairly high PF rating.

In the previously mentioned "Tech/Ops" report (Reference A-f), Chapter 5 describes how a minimum-type improvised basement shelter might be constructed in a relatively short time, that is, a basement shelter that will afford a protection factor of 100.

In an RTI Final Report entitled Crash Civil Defense Program Study (Reference A-h) a number of important parameters which should be considered in crash CD planning included such factors as geographic areas, seasonal and climatic limitations, time element, population mobilization and mobility, and so forth. If it is known, for example, that a particular area could handle a large percentage of its population in residential basements, pre-planning for crash civil defense may lead in one direction as opposed to an area of the country where the scarcity of basements is known. Or, a particular community may have developed a CD plan based on the assumption that its population could move to public shelters and yet weather conditions at the time of attack were such as to restrict or prevent movement. In such a situation, basements would take on a new importance.

VI. SUMMARY

It has been the purpose of this paper to examine Bureau of the Census residential basement data and to investigate its applicability to damage assessment routines. While some cautions were pointed out in using the data, especially overlap, it is concluded that for most purposes the U. S. Census basement data complements the NFSS data and improves on previous information. For this reason it is urged that such programs as Jumbo III and others, incorporate this later and more accurate data.

VII. APPENDIX A REFERENCES

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Annex A-1

Population, Shelter Space, and Basement Data - 180 Tracted Areas

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	% of Pop. Assignable to Surveyed Shelters Cat. 2-8	% of Pop. Assignable to Residential Basements
1	Bridgeport, Conn.	334,576	103%	40%	85%
	Hartford, Conn.	525,207	228	169	88
	New Britain, Conn.	129,397	93	54	85
	New Haven, Conn.	311,681	159	94	89
	Norwalk, Conn.	96,756	30	11	83
	Stamford, Conn.	178,409	108	36	82
	Waterbury, Conn.	181,638	110	59	88
	Portland, Main	120,655	135	88	97
	Boston, Mass.	2,589,302	239	132	90
	Brockton, Mass.	157,231	32	10	85
	Fall River, Mass.	116,044	56	19	115
	Lawrence - Haverhill, Mass.	187,601	102	42	95
	Lowell, Mass	157,982	70	27	85
	New Bedford, Mass	166,847	67	29	87
	Pittsfield, Mass.	73,839	56	33	90
	Springfield - Chicopee - Holyoke, Mass.	478,592	97	43	90
	Worcester, Mass.	323,306	114	52	86
	Manchester, N. H.	88,282	92	49	101

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
1	Atlantic City, N. J.	160,880	246%	190%	59%
	Jersey City, N. J.	610,734	234	104	95
	Middlesex County, N. J.	433,856	66	35	73
	Newark, N. J.	1,689,420	187	93	90
	Paterson - Clifton - Passaic, N. J.	1,186,873	76	33	88
	Somerset County, N. J.	143,913	41	26	78
	Trenton, N. J.	266,392	122	73	81
	Albany - Schenectady - Troy, N. Y.	657,503	161	98	90
	Binghamton, N. Y.	212,661	79	34	87
	Buffalo, N. Y.	1,306,957	126	67	79
	New York, N. Y.	10,694,175	558	335	96
	Rochester, N. Y.	586,387	246	149	91
	Syracuse, N. Y.	563,781	102	50	84
	Utica - Rome, N. Y.	330,771	66	30	87
	Mayaquey, P. R.	83,850	32	18	-*
	Ponce, P. R.	145,586	22	8	-
	San Juan, P. R.	588,805	116	70	-
	Providence - Pawtucket, R. I.	816,148	92	59	92

* None Listed

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
2	Wilmington, Del.	366,157	126%	73%	69%
	Washington, D. C.	2,001,897	364	226	73
	Lexington, Ky.	131,906	121	68	42
	Louisville, Ky.	725,139	140	79	53
	Baltimore, Md.	1,727,023	129	79	76
	Akron, Ohio	513,569	136	83	82
	Canton, Ohio	340,345	39	20	84
	Cincinnati, Ohio	1,071,624	177	117	88
	Cleveland, Ohio	1,796,595	161	98	84
	Columbus, Ohio	682,962	97	67	76
	Dayton, Ohio	694,623	77	40	63
	Hamilton - Middleton, Ohio	199,076	63	37	70
	Lima, Ohio	103,691	48	24	66
	Lorain - Elyria, Ohio	217,500	35	10	63
	Springfield, Ohio	131,440	92	56	70
	Steubenville - Weirton, Ohio	167,756	29	23	79
	Toledo, Ohio	456,931	143	69	71
	Youngstown - Warren, Ohio	509,006	60	33	78

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	% of Pop. Assignable to Surveyed Shelters Cat. 2-8	% of Pop. Assignable to Residential Basements
2	Allentown - Bethlehem - Easton, Pa.	492,168	84%	46%	87%
	Altoona, Pa.	137,270	52	28	87
	Erie, Pa.	250,682	72	35	83
	Harrisburg, Pa.	345,071	126	84	85
	Johnstown, Pa.	280,733	48	22	81
	Lancaster, Pa.	278,359	70	47	82
	Philadelphia, Pa.	4,342,897	175	110	82
	Pittsburgh, Pa.	2,405,435	132	91	85
	Reading, Pa.	275,414	114	60	91
	Scranton, Pa.	234,531	80	42	92
	Wilkes - Barre - Hazleton, Pa.	346,972	54	30	93
	York, Pa.	238,336	47	24	87
	Newport News - Hampton, Va.	224,503	31	13	7
	Norfolk - Portsmouth, Va.	578,507	98	64	10
	Richmond, Va.	408,494	169	96	29
	Wheeling, West Va.	190,342	84	50	81
3	Birmingham, Ala.	634,864	71	34	25
	Gadsden, Ala.	96,980	22	10	10
	Mobile, Ala.	314,301	37	14	2
	Montgomery, Ala.	169,210	69	38	4

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
3	Jacksonville, Fla.	455,411	100%	59	2
	Miami, Fla.	935,047	108	48	2
	Orlando, Fla.	318,487	21	10	2
	Tampa - St. Petersburg, Fla.	772,453	36	15	1
	Atlanta, Ga.	1,017,188	137	80	35
	Augusta, Ga.	216,639	58	15	7
	Columbus, Ga.	217,985	32	12	6
	Macon, Ga.	180,403	51	18	9
	Savannah, Ga.	188,299	39	15	3
	Charlotte, N. C.	272,111	92	46	20
	Durham, N. C.	111,995	173	101	20
	Greensboro - High Point, N. C.	246,520	69	37	24
	Raleigh, N. C.	169,082	99	48	24
	Winston-Salem, N. C.	189,428	92	47	46
	Charleston, S. C.	216,382	39	15	4
	Columbia, S. C.	260,828	90	50	9
	Greenville, S. C.	209,776	81	44	19
	Chattanooga, Tenn.	283,169	59	33	29
	Knoxville, Tenn.	368,080	123	58	38
	Memphis, Tenn.	627,019	92	48	13
	Nashville, Tenn.	399,743	168	93	34

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
4	Chicago, Ill.	6,220,913	245%	177%	82%
	Decatur, Ill.	118,257	72	32	73
	Peoria, Ill.	288,833	106	72	75
	Rockford, Ill.	209,765	46	23	79
	Evansville, Ind.	199,313	97	60	52
	Fort Wayne, Ind.	232,196	89	43	67
	Gary - Hammond, Ind.	573,548	37	18	63
	Indianapolis, Ind.	697,567	206	113	65
	Muncie, Ind.	110,938	22	11	44
	South Bend, Ind.	238,614	91	44	74
	Ann Arbor, Mich.	172,440	199	110	70
	Detroit, Mich.	3,762,360	116	66	75
	Flint, Mich.	374,313	65	24	68
	Grand Rapids, Mich.	363,187	61	31	84
	Jackson, Mich.	131,994	72	41	73
	Kalamazoo, Mich.	169,712	61	25	77
	Lansing, Mich.	298,949	93	40	74
	Muskegon - Muskegon Heights, Mich.	149,943	31	10	62
	Saginaw, Mich.	190,752	32	13	50
	Kansas City, Mo.	1,039,493	221	145	81
	St. Louis, Mo.	2,060,103	171	102	80
	Springfield, Mo.	126,276	88	37	39

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	% of Pop. Assignable to Surveyed Shelters Cat. 2-8	% of Pop. Assignable to Residential Basements
4	Green Bay, Wis.	125,082	153%	96%	75%
	Madison, Wis.	222,095	193	130	83
	Milwaukee, Wis.	1,194,290	186	107	89
5	Fort Smith, Ark.	66,685	57	27	7
	Little Rock - North Little Rock, Ark.	242,980	126	68	9
	Baton Rouge, La.	230,058	48	21	1
	Monroe, La.	96,968	37	8	1
	New Orleans, La.	868,480	116	73	5
	Shreveport, La.	281,481	100	65	2
	Albuquerque, N. M.	262,199	43	23	8
	Oklahoma City, Okla.	511,833	158	101	13
	Tulsa, Okla.	418,974	105	59	15
	Abilene, Tex.	120,377	43	12	2
	Austin, Tex.	212,136	142	79	4
	Beaumont - Port Arthur, Tex.	306,016	39	13	1
	Corpus Cristi, Texas	221,573	48	19	1
	Dallas, Tex.	1,083,601	128	75	2
	El Paso, Tex.	314,070	74	42	12
	Fort Worth, Tex.	573,215	105	54	3
	Galveston - Texas City, Tex.	140,364	98	38	5

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
5	Houston, Tex.	1,243,158	110%	57%	1%
	Laredo, Tex.	64,791	46	32	2
	Lubbock, Tex.	156,271	46	27	3
	Odessa, Tex.	90,995	15	5	1
	San Angelo, Tex.	64,630	48	18	3
	San Antonio, Tex.	687,151	71	39	2
	Texarkana, Tex.	91,657	32	23	2
	Tyler, Tex.	86,350	44	15	2
	Waco, Tex.	150,091	69	32	2
	Witchita Falls, Tex.	129,638	55	21	2
6	Colorado Springs, Colo.	143,742	78	41	52
	Denver, Colo.	929,383	119	68	64
	Pueblo, Colo.	118,707	38	17	49
	Davenport - Rock Island - Moline, Iowa	270,058	130	72	73
	Des Moines, Iowa	266,315	168	103	100
	Sioux City, Iowa	107,849	94	55	85
	Waterloo, Iowa	122,482	128	79	81
	Topeka, Ka.	141,286	149	81	63
	Wichita, Ka.	343,231	103	58	46
	Duluth, Minn.	276,596	170	109	79
	Minneapolis - St. Paul, Minn.	1,482,030	116	72	87

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
6	Lincoln, Neb.	155,272	107%	58%	83%
	Omaha, Neb.	457,873	171	130	82
7	Phoenix, Ariz.	663,510	44	22	3
	Tucson, Ariz.	265,660	25	10	4
	Bakersfield, Calif.	291,984	30	16	6
	Fresno, Calif.	365,945	27	14	14
	Los Angeles - Long Beach, Calif.	6,742,696	82	53	1
	Sacremento, Calif.	502,778	81	49	14
	San Bernardino - Riverside - Ontario, Calif.	809,782	115	65	8
	San Diego, Calif.	1,033,011	38	20	7
	San Francisco - Oakland, Calif.	2,783,359	164	95	5
	San Jose, Calif.	642,315	31	14	18
	Santa Barbara, Calif.	168,962	17	6	10
	Stockton, Calif.	249,989	24	11	24
	Honolulu, Hawaii	500,409	76	36	8
	Las Vegas, Nev.	127,016	51	38	3
	Ogden, Utah	110,744	50	27	45
	Salt Lake City, Utah	383,035	103	59	62
8	Portland, Oreg.	821,897	131	79	64

Annex A-1 (Continued)

Region	SMSA	Population	% of Pop. Assignable to Surveyed Shelters Cat. 1-8	Cat. 2-8	% of Pop. Assignable to Residential Basements
8	Seattle, Wash.	1,107,213	135%	76%	61%
	Spokane, Wash.	278,333	92	57	82
	Tacoma, Wash.	321,590	78	41	36
	TOTAL	109,406,118			

Annex A-2

SUMMARY COMPARISON BY OCD REGION OF 180 TRACTED REPORTS AND THE UNITED STATES

Region	Tracted Areas				Total Regional Shelter Spaces	
	Number of Tracted Areas	Population	Categories 1-8	Categories 2-8	Categories 1-8	Categories 2-8
1	36	26,696,037	83,241,648	48,612,820	84,315,259	48,654,057
2	34	22,866,954	33,823,375	21,372,095	35,465,957	21,588,242
3	25	8,871,400	7,533,147	3,867,931	10,776,321	5,296,763
4	25	19,270,933	32,688,666	21,001,432	33,467,443	21,233,883
5	27	8,715,742	8,309,202	4,618,311	9,883,870	5,360,722
6	13	4,814,824	6,009,882	3,699,676	11,671,619	6,562,755
7	16	15,641,195	12,709,225	7,602,971	13,003,881	7,707,112
8	4	2,529,033	3,081,131	1,709,821	4,585,024	2,519,884
TOTALS	180	109,406,118	187,396,276	112,485,057	203,169,374	118,923,418

Appendix B

Electric Power Availability in the

Postattack Period

This Appendix was originally submitted to OCD as Research Memorandum RM 82-5,* except for minor editorial changes.

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* D. L. Hall, E. L. Hill, and P. S. McMullan, Electric Power Availability in the Postattack Period. Research Memorandum RM 82-5, (Durham, North Carolina: Research Triangle Institute, Operations Research Division, 12 November 1962).

Appendix B

Electric Power Availability in the Postattack Period

I. SUMMARY AND CONCLUSIONS

A. Introduction

A request was received from the Shelter Surveys and Shelter Research Divisions of the Office of Civil Defense to assist them in preparing a data collection form which could be completed by power company engineers for the purpose of computing the protection factor in essential operating areas of electric power plants. After detailed discussions with personnel at OCD, it was agreed to interpret this request in its broadest sense, namely: identify the critical factors required for determining the postattack availability of electric power in communities of the United States.

Shortly after RTI initiated this project, it was learned from OCD that there was probable duplication by the Department of Interior. For this reason the RTI effort was terminated in its early phases and the conclusions drawn are preliminary.

B. Data Requirements

A preliminary analysis shows that the determination of the postattack availability of electric power in a community requires forecasts of: (1) the vulnerability of the power system components to blast and fire damage by nuclear explosions, (2) the ability of key operators to carry out specific functions in a radioactive fallout environment, (3) the interconnections and redundancy of the power network connecting the power sources and the consumer, (4) the load requirements imposed on the surviving elements of the power system, and (5) the kilowatt-hours of generating capacity before the fuel supply is depleted.

C. Power System Analysis

The detailed characteristics of a single large electric power system (Duke Power Company) were briefly analyzed, and results tentatively generalized.

1. Relevant Features of Electric Power Systems - A description of the relevant features of electric power systems is presented in Section II.

2. Power Plant Operation - An examination of the operating requirements shows that in all thermoelectric power plants, the personnel stationed in the control room are critical to the operation of the plant. Therefore, special attention was devoted to the method and data required to calculate the protection factor at this location. A more detailed discussion of these aspects is given in Section III.

3. Power Distribution Networks - An examination of the location of power plants and the interconnecting transmission and distribution networks, as given on the Federal Power Commission maps (Reference B-a) led to the establishment of certain general characteristics of the networks which were pertinent to the determination of power availability in the U. S. These characteristics were found to exist in the Duke Power Company system and a closer analysis of the effect of a nuclear attack on the generation and transmission systems in the Charlotte, North Carolina area was made. This phase of the analysis is presented in Section IV.

D. Summary

Because of the redundancy in typical transmission systems, it can be assumed in most cases that if a community has not received extensive damage from the nuclear blast, there will be transmission lines to carry power to it. If the capacity of a power system has been reduced because of: (1) physical damage to lines, generating stations, etc.; (2) shortage of fuel because of fallout hazard to exposed workers, transportation system damage, etc.; or (3) inadequate protection from fallout at the generating stations; then the load must also be reduced by the same cause. It can be expected that there will be a sizeable reduction in power demand in most communities since industrial users of power will be virtually closed down.

No estimate of the expected demand for power in a fallout environment has been made. Demand will vary from community to community and its estimation requires an analysis of the characteristics of individual systems in the U. S.

E. Conclusions

Data collection of factors required for calculating protection factors of power plants is more complex than for most other types of buildings. Hence, it is infeasible to request such data from power company personnel who are not normally graduates of the OCD Fallout Shelter Analysis Program.

To determine the postattack power capacity in the U. S. will require an on-site survey of each major power plant. The survey would accomplish three objectives:

1. Determine the length of time the plant could operate at various load factors on normal fuel inventories.

2. Determine the protection factor for critical operating locations in the power plant.

3. Determine the modifications, if needed, for improving the protection factor at critical locations to acceptable levels.

Closer analyses of the characteristics of a small number of representative power systems need to be made. Such analyses would establish a more firm basis for the above conclusions or would modify them, and would establish firm methods for determining:

1. The vulnerability of power system components to blast and fire damage by nuclear explosions, (Reference B-b).

2. The interconnections and redundancy of the power network connecting the power sources and the consumer.

3. The load factors which will be imposed on the power systems during the postattack period.

4. The power generating capacity of the power system during the postattack period.

II. CHARACTERISTICS OF ELECTRIC POWER SYSTEMS

A. Electric Power Systems

An electric power system will in general consist of a number of generating stations (thermoelectric and/or hydroelectric) dispersed geographically so they are accessible to a supply of fuel or water power and condenser water. The location of demand is also a factor in selecting plant locations. Duke Power Company, for example, serves an area approximately 300 by 100 miles with power generated at 29 hydroelectric and 8 thermoelectric stations. The generating stations and the loads are interconnected by means of high voltage transmission lines, transformers, switch gear, and communication links. Generally, there is a central control station where the load demand throughout the system is monitored and the power output from each of the generating stations is adjusted. Switch gear at junction points of the distribution system can also be controlled from the central control station. Thus, faults in the system can be isolated from the power sources so that maximum protection to the system and minimum amount of power failure to the consumer is achieved. To disrupt the power in certain areas would require shutting down almost all generating stations or disabling multiple links of transmission lines and substations.

In addition to the power company's generating stations, there are industrial power generators which are tied into the system. These industrial stations both buy and sell power to the power company according to the load demands. Also, there is normally a tie-in with adjacent power companies. Duke Power Company is tied in with Carolina Power & Light Company on the east, Virginia Electric & Power Company on the north, and South Carolina Electric & Gas Company on the south.

B. Power Generating Stations

Except for a few nuclear power plants and some small internal combustion engine driven generating plants, the power stations in the United States are either hydroelectric or thermoelectric.

The steam generators, turbines, condensers, etc., are housed in one building which is often equal in height to a 6 or 8 story building.

1. Thermoelectric Plants - Critical parts of a thermoelectric plant from the standpoint of physical vulnerability to nuclear blast and of protecting personnel from the effects of fallout are: fuel, air, and location of personnel.

a. Fuel Supply - When coal is the primary source of fuel, it is stored in a yard near the generator building and brought to the furnace by means of draglines or bulldozers, and conveyors. A dragline or bulldozer brings the coal from the coal piles to a spot where a conveyor carries it to the top of the power plant. The dragline operator may be located in a light-weight frame building near the base of the conveyor. If a bulldozer is used, the bulldozer operator would be completely exposed. Although coal is stored in a hopper in the generator building prior to being pulverized, it is not common that enough fuel would be stored at this point to operate the furnace for more than a few hours. The amount of fuel available without requiring the exposure of power plant personnel to radiation outside the protected areas is a critical factor in determining how long the plant will be able to operate after a nuclear attack.

The conveyor and the housing for the dragline operator is generally of light construction and could be a critically vulnerable point to the direct blast effects of a nuclear detonation.

In some cases, modern power generating systems have the capability of using more than one type of fuel. If this is the case and if the supply

of the alternate fuel can be assured, the amount of shielding provided to the dragline operator and the vulnerability of the coal conveyor would be of less importance.

b. Air Supply - Large quantities of air are used for combustion of the fuel and often for the cooling of generators. This air may carry radioactive contamination into the power plant and endanger the lives of the operators.

c. Water Supply - Water is required in the operation of boilers and condensers in thermoelectric power plants. Boiler feedwater is not used in great quantities, but it must be properly treated to remove the rust and scale-forming impurities. The exposure of the feedwater technician to fallout may be a critical factor in determining the capability of the plant during the postattack period.

Condenser water is usually obtained directly from the stream or lake adjoining the generator station. This water is generally passed through a course screen where trash and other large objects are trapped before being passed through the condenser. If the water supply contains much trash, the screens must be cleaned frequently or the capacity of the generating system will be considerably reduced. The location of the screens, the required frequency of cleaning, and the capability of the system to operate even though the screens are clogged are all important factors.

d. Operating Personnel - In most modern power plants, the operation of the plant is highly automated. Nevertheless, operating personnel are required for monitoring the operation and making periodic adjustments. Some of these personnel are stationed in a control room. The protection factor of this room, as well as the ability of the power system to operate with less than the normal number of personnel, are important factors in determining the ability of the generating stations to supply power.

2. Hydroelectric Power Stations - The operation of a hydroelectric power station is considerably less complicated than thermoelectric stations. Generally, the plant can operate for an indefinite period without attention. Therefore, it should be determined first if the plant will operate automatically; if it cannot, the protection factor provided to personnel critical to its operation may be the determining factor.

C. Transmission and Distribution Systems

Immediately outside the power generating station is a substation containing disconnect switches, circuit breakers, lightning protection equipment, etc. All power from a generating station passes through this substation where it is transformed to a higher voltage and transmitted to the high voltage transmission lines. Although the transformers and switch gear, which are rather bulky and heavy, may be quite invulnerable to nuclear blast effects, the insulators, bus bars and associated superstructure may be the most vulnerable part of the power station. Most of the circuit breakers and disconnect switches are remotely operated from the power station control room. If the control equipment, the associated wiring, or any of the high voltage equipment in this substation were damaged, the power station might be effectively isolated from the transmission and distribution system.

The transmission of power from the power generating stations to the consumer is made over a network made up of transmission lines, transformers, and switch gear. This network may be in the form of a tree where the transmission lines and substations are in series and each must be in an operating condition for the power to reach the ultimate consumer. More generally, however, there are several power plants, and the network is in the form of a grid or ring where multiple paths are available for delivering the power from power stations to the consumer. The switch gear and circuit breakers are located at various nodes or substations of the transmission system and are remotely controlled from the master control points so that faults on the line can be isolated and the area affected by the fault minimized.

III. COMPUTATION OF PROTECTION FACTORS FOR POWER PLANT PERSONNEL IN CRITICAL AREAS

A. Control Rooms

Regardless of the extent of the automated or remotely controlled equipment, the control room of a thermoelectric power plant is critical to the operation of the plant. Operators must be on duty in this location whenever the plant is generating power.

In some cases there is more than one control room for the plant; each room would control specific boilers and generators. In such cases each control room should be treated separately.

The location of the control room varies from power plant to power plant. In the older plants it is generally located so that it overlooks the turbine room; in more modern plants, it may be anywhere. Often it is located so that one or more sides of the room are shielded by a complicated maze of pipes, furnace and boiler structure, coal hoppers, and a massive turbine generator. In some cases it will be situated in a structure comparable in height to a six to eight story building. Directly overhead may be only the light-weight ceiling of the control room, pipes, expanded metal catwalks and the heavier roof of the plant. In this case, however, the sides of the control room are likely to be shielded all the way to the roof by the heavy structure of the boiler and furnace.

In some cases the control room may be located in a smaller building adjoining the power plant proper. With this arrangement the control room would be surrounded on three sides by a conventional office type building and on the fourth side by the power plant.

B. Other Critical Locations

In some plants it is necessary for a man to be in the turbine room to monitor the turbine operations and to manually adjust the opening of the steam valves when a unit is being put into operation. When an operator is required in the turbine

room, the protection factor therein will be critical.

If a bulldozer is required to move the coal from the bunker to the conveyor, or if a dragline operator performs the same function from a lightly constructed building, it would generally be found in either case that it would not be safe for the operator. Therefore, a more important consideration is the amount of coal available to the furnaces. This fuel supply will determine how many kilowatt-hours the power plant can produce before the fuel is depleted.

C. Computation of Protection Factors for Critical Areas of Power Plants

As mentioned in the foregoing sections, the critical areas of a power plant from the standpoint of protection factors are the control rooms and sometimes the turbine room. The problems associated with the computation of protection factors for these areas are complicated by three basic considerations: (1) the determinations of the mass thicknesses of walls, pipes, boilers, turbo-generators, etc., are extremely difficult; (2) adopting the existing NBS Computer Program Method of PF computations for such a structure with irregular mass thicknesses introduces inaccuracies as well as uncertainties in the results, (Reference B-c); (3) since the problem will vary so greatly from one situation to the next, it is difficult to conceive of a standard and universal form of collecting the data needed for the PF computation.

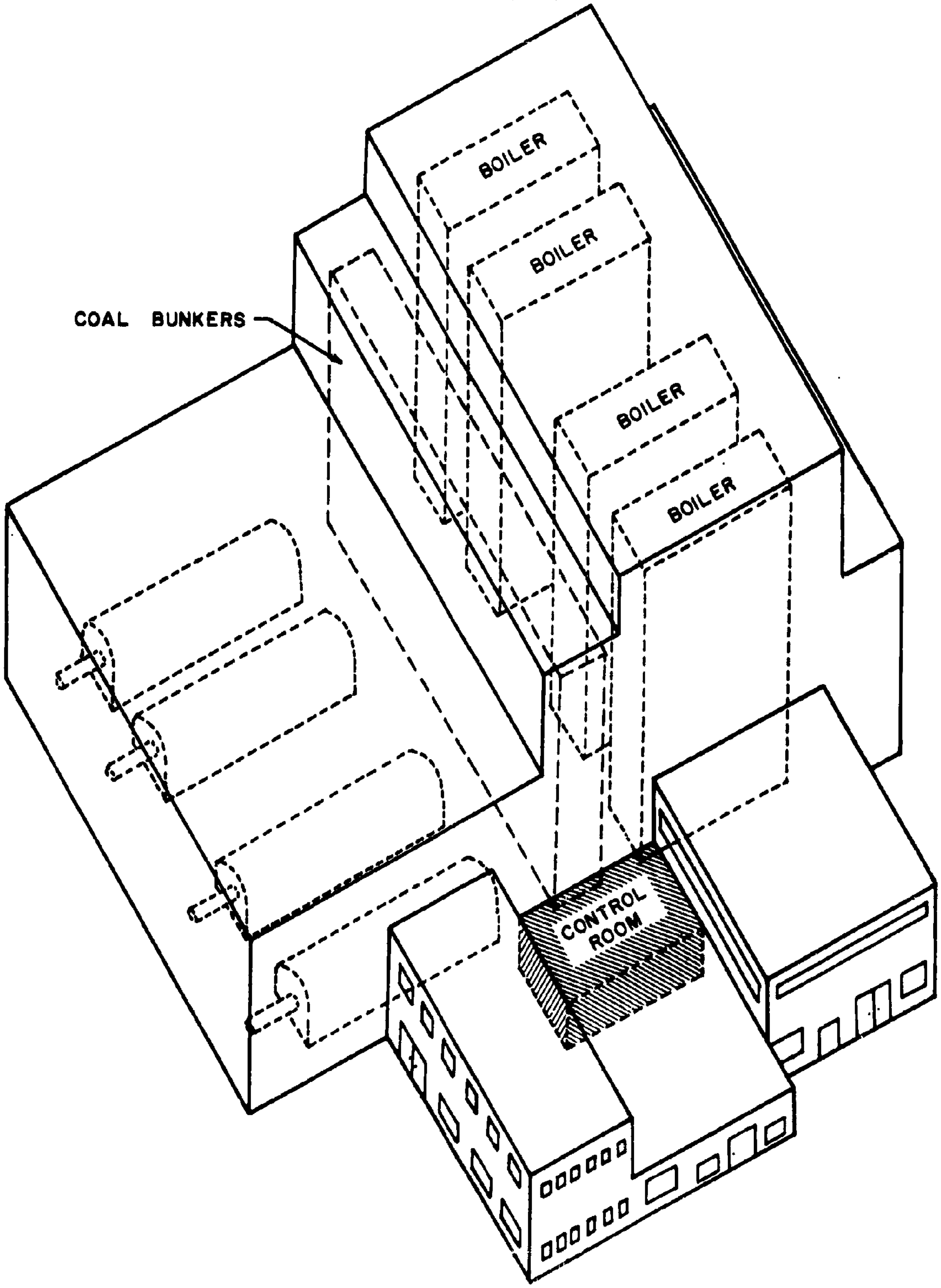
These facts can best be understood by examining the methods required for a PF computation of a plant in North Carolina.

1. Example PF Computations - Figure B-1 shows a typical power plant with a control room over-looking the turbine room. The location of massive structures such as turbogenerators and boilers is shown. In this plant there were two control rooms, one located as shown in Figure B-1 and the other between two of the boilers. In another plant, the control room was located about 15 feet above the turbine room floor on the outside wall.

Computation of the roof and wall contribution by the NBS Computer Program Method would be very misleading, since it requires assigning an average mass thickness for partitions and walls. The average mass thicknesses of the turbines, coal bunkers,

FIGURE B-1

Typical Power Plant Layout



and boilers for example, could mean that no radiation would enter the control room from the power plant side. There are, however, significant open spaces between the control room and the outside through which radiation could "shine", even though there were areas which would be completely shielded from radiation.

It was decided, therefore, to divide the area into azimuthal sectors in which parts of the structure could be assigned various mass thicknesses. All weights greater than 320 psf were considered as heavy enough to exclude all significant radiation. This simplification eliminated the necessity of determing the exact weight of most of the structure. In Figure B-1, for example, it can be determined by inspection that the area between the control room and the outside wall is either 0 or in excess of 320 psf.

2. Conclusions - From these considerations, it was concluded that:

a. The use of azimuthal sectors in computing ground contribution provides the most accurate results in such complex structures. (The NBS Computer Program can handle only one mass thickness per wall.)

b. The dimensions of the azimuthal sectors would best be obtained by a combination of visual inspection and readings from engineering drawings. For example, the azimuthal sectors between the boilers and the coal bunkers could be measured from the engineering drawings, but the percentage of free opening (not obstructed by heavy piping, etc.) could best be estimated visually.

c. To provide a form that could be sent to all power plants would require one so detailed that there is a strong likelihood that inaccurate and misleading results would be obtained. Furthermore, to require the data collected to be in keeping with that required by a stereotyped form could result in an unnecessary amount of effort by a power company engineer and might result in their refusing to provide this data.

d. The determination of the protection factor could best be made at the time of the data collection survey. It should be done by a specially trained engineer who is equipped with the necessary charts, tables, and procedures for making the computations. Immediately following the survey, and while the engineer is still at the power plant, he could determine his recommendations for increasing the protection factor to some prescribed level.

e. The PF of the "best available" shelter in the plant should be determined so that workers can work in shifts with most of their stay time in the best protected area.

f. The expected availability of fuel should also be determined and the length of time the power plant can operate at various load levels (10%-50%) should be computed from information obtained through discussions with the plant superintendent. Any special operating problems such as bringing new units on the line under a condition of fallout would thus be revealed.

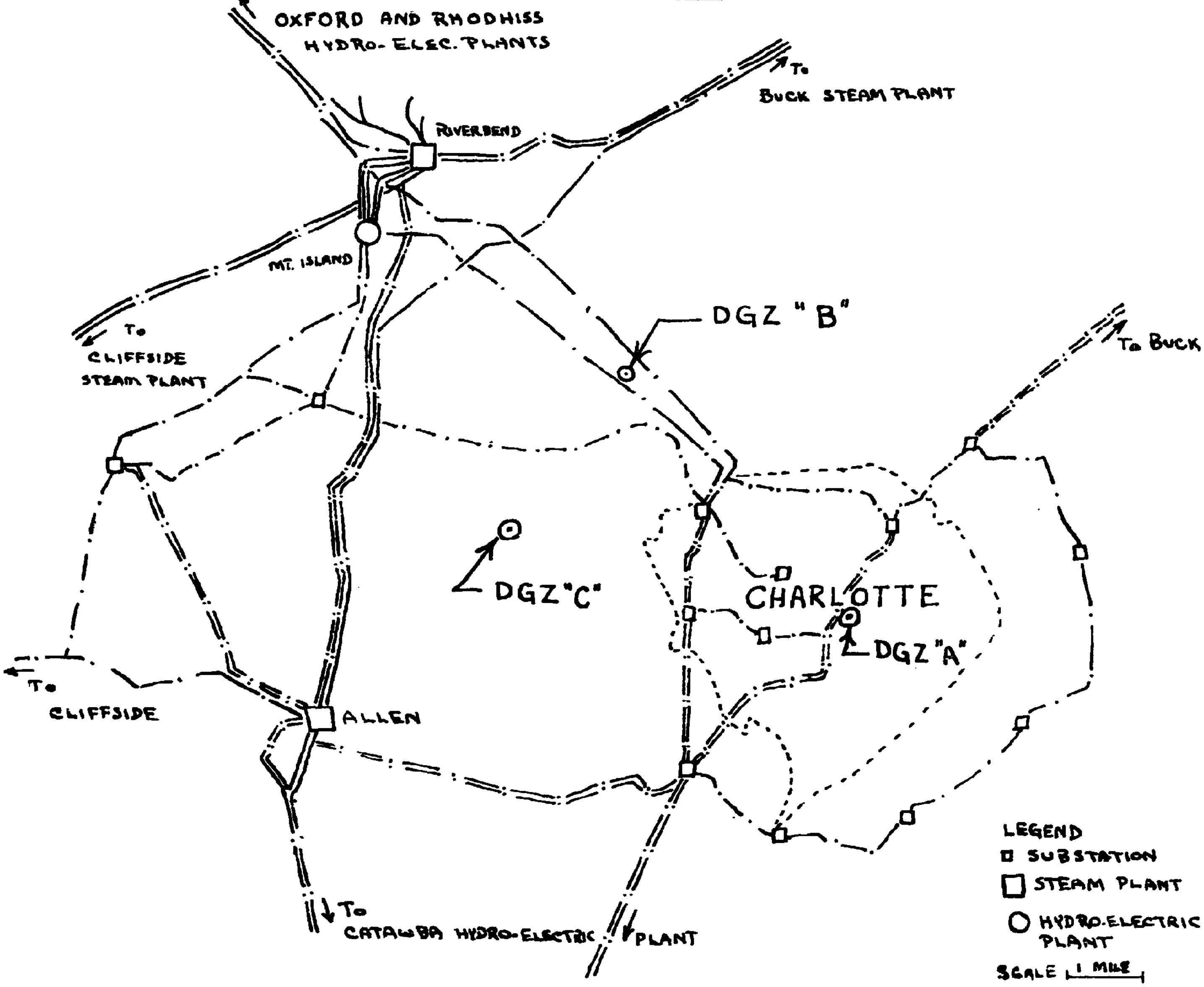
IV. THE EFFECTS OF A NUCLEAR ATTACK ON ELECTRIC TRANSMISSION AND DISTRIBUTION SYSTEMS

As mentioned earlier, a power system generally consists of a number of power plants separated geographically and connected electrically to the consumer areas by multiple path transmission lines and substations. A cursory examination of the power system as shown on FPC maps of principal electric facilities in the U. S. indicates that it would be very difficult for a major community to be isolated from a power source without being destroyed itself. This factor was illustrated by a detailed examination of the electric system of Charlotte and immediate surrounding area.

The power system supplying Charlotte is shown on the map in Figure B-2. The effect of an attack on the city and the power system is a function of the yield and effects radius, the Circular Probable Error (CEP), and the location of the aimpoint

FIGURE B-2

Location of Ground Zeros



or Designated Ground Zero (DGZ). For this illustration, an airburst of a 5 megaton weapon and a CEP of 1.5 miles were assumed. Five psi was also assumed to be required to disrupt service from power lines and substations (Reference B-d) and to cause heavy damage to the city. The aimpoint was chosen differently for three different cases:

<u>Case A</u>: Aimpoint was taken as the center of Charlotte at the point marked A. The probability of destroying both the Allen Plant and all the distribution stations around Charlotte was computed to be .233. The probability that all of Charlotte would receive extensive damage is greater than .95.

<u>Case B</u>: The DGZ was taken midway between the River Bend Plant and Charlotte at the point designated by the letter B. It was found that the probability of simultaneously destroying River Bend, Mt. Island, and Mt. Holly power plants; and Maplehurst and North Junction substations was .96. When these substations are destroyed, about 85% of the city also would receive major damage.

<u>Case C</u>: If the aimpoint is taken so as to maximize the damage to Charlotte's distribution systems and both the Allen and River Bend power plants, the DGZ will be at point C. With this aimpoint, the probability of accomplishing this objective is .89 and at least 85% of the city would receive major damage.

V. APPENDIX B REFERENCES

B-a. Federal Power Commission. Principal Electric Facilities Maps. Washington: Bureau of Power, 1961.

B-b. U. S. Air Force, Nuclear Weapons Employment Handbook, AFM 200-8 (Confidential). Washington: Department of the Air Force, October 30, 1961.

B-c. L. V. Spencer and C. Eisenhauer. Calculation of Protection Factors for the National Fallout Shelter Survey. National Bureau of Standards Report 7539. Washington: U. S. Department of Commerce, July 3, 1962.

B-d. R. V. H. Wood, A. C. Werden, Jr., and R. L. Berg. Effects of Atomic Weapons on Electric Utilities. Operation Teapot Preliminary Report ITR-1173, Project 35.1, Federal Civil Defense Administration, May, 1955.

Appendix C

<u>An Attack Environment III</u>

<u>Data Summary Technique</u>

This Appendix was originally submitted to OCD as Research Memorandum RM-82-6*, except for minor editorial changes.

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* John H. Neblett, An Attack Environment III Data Summary Technique, Research Memorandum RM-82-6, (Durham, North Carolina: Research Triangle Institute, Operations Research Division, 18 March 1963).

Appendix C

AE III Data Processing Technique

I. INTRODUCTION

The objectives of OCD Project 4613A, Improvement of Protection Data Base for Damage Assessment, include the development of procedures to be used in the analysis of civil defense shelter systems. This appendix will propose a data processing technique which will assist in such development.

A. Background to the Problem

The proposed technique is offered in response to a desire expressed by the director, Systems Evaluation Division, for a way to obtain a reasonably accurate distribution of people under specific attack environment criteria for a specified attack pattern. He further indicated that a procedure for obtaining such information from the Jumbo III damage assessment system was not available.

Because of previous involvement with the Jumbo III system, RTI has available a printout of an Attack Environment III run. The Attack Environment III program is that part of the Jumbo III system in which the desired environment criteria first become available. An interpretation of the printout shows that the desired information is available in the AE III output tape and that the information can be extracted and placed in a reasonable format by an additional computer program.

B. Context of the Present Appendix

The specific presently-available environment criteria of interest are over-pressure, reference fallout intensity, and fallout arrival time. When the

Jumbo III system is run using the population resource file, these criteria can be obtained for one point within each standard location in the United States. The standard location code permits summary levels by area, state, and OCD region to be made without difficulty. However, simple summary tables showing numbers of people under a range of overpressure, initial intensity and time of arrival will not likely permit the reasonably accurate specification of the attack environment desired for systems analysis. For example, such summaries at a State level would not maintain the relationship between time of arrival and initial intensity required for determination of the total or equivalent residual dose. Also the relationship between overpressure and the other criteria should be maintained as much as possible in order to eliminate from the analysis of fallout casualties the appropriate number of blast casualties.

Such considerations as those listed above led to the suggested technique which follows in the body of this appendix. In it a technique is proposed in which the environment criteria are extracted in a three dimensional matrix. This matrix will maintain the interrelationships among the criteria much better than would a simple summary for each criterion.

C. Output Illustration

The format shown in Figure C-1 will illustrate the type of information which can be obtained from AE III. It also serves as an example of the type of format which may be used.

In the page shown, the title information indicates that this is a sheet from the state summary output listing, State of Virginia. Page 3 of 20 indicates that there are 20 separate overpressure (psi) ranges, two less than 5 ± 1 psi and 17 greater than 5 ± 1 psi. The entries in the table indicate the number of people in Virginia exposed to a given range of overpressure, H + 1 intensity, and time of arrival. For example, the entry in

FIGURE C-1

Attack Environment Summary

Sample Page

STATE SUMMARY

Virginia

Page 3 of 20
Average psi 5 ± 1

Average Time of Arrival Hr. After Attack ±½

	Reference Intensity						
	0 to 3	3 to 10	10 to 100	100 to 300 - - - -	- -	- -	-over 30,000
Less than ½	100	150	500	-	-	-	-
1	200	175	-	-	-	-	-
2	600	300	-	-	-	-	-
3	500	-	-	-	-	-	-
4	-	-	-	-	-	-	-
-							
-							
-							
-							
-							
-							
-							
-							
-							
-							
-							
-							
35 & over							

- Population Exposed -

the first row, first column is 100. This indicates that in Virginia for the particular attack from which this information was derived, there are 100 people who are subjected to 5 $\pm$ 1 psi, 0 to 3 R/hr. initial intensity and less than 1/2 hour arrival time. The entry in the same column but one row lower shows 200 people with the same psi and intensity, but with a 1 $\pm$ 1/2 hour arrival time.

The sample page is chosen to illustrate a state summary book. A sample page from a region or area summary book would be quite similar. All or any one of the summary books could be prepared when required for the evaluations to be made. The basic format could be changed to show overpressure in the rows and reference intensity in the columns with a page for each time of arrival. In other words, the method of presentation can be varied to suit the needs of the evaluation.

The total number of entries within any summary book will depend upon the number of range intervals chosen to represent each criterion. Condensing can be accomplished by limiting the number of range intervals to those essential for the type of investigation in question.

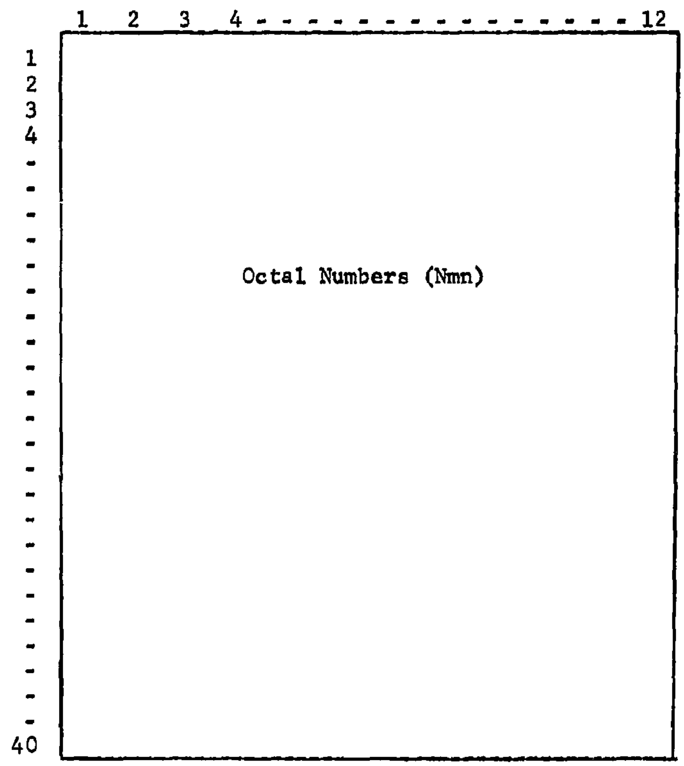
II. PROCEDURE

The computer algorithm for developing the basic information into a reference document for planning data is as follows:

A. The output tape of Attack Environment III is divided into data blocks, each block consisting of 40 words; each word consists of 12 octal digits, which describe the situation in a standard location (Figure C-2).

FIGURE C-2

AE III Magnetic Tape Data Block



The particular Octal numbers (Nmn) in the data block (Figure C-2), which are of interest in this analysis are listed:

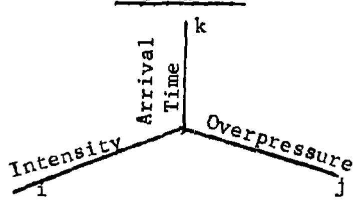
Region	Word 1	Digits 7,8
State	" 1	" 9,10
Area	" 1	" 11,12
County	" 2	" 1,2
Effective overpressure in psi	" 8	" 3 to 7
Standard Location	" 2	" 3 to 10
Urban/Rural Index	" 2	" 11,12
Intensity at (H + 1)	" 11	" 3 to 7
Time of Arrival	" 10	" 8 to 12
People	" 13	" 1 to 12

B. A geometric representation of the sort-summary problem would be a three dimensional matrix (Figure C-3). As an illustration, subject to revision, the following scale intervals are chosen:

1. The i, or radiation intensity scale will be divided into ten segments: 0; 3; 10; 100; 300; 600; 1000; 3000; 10,000; and over 30,000 R/hr.
2. The j, or overpressure scale will be divided into five psi increments, zero to 100.
3. The k, or time of arrival scale will be divided into one hr. intervals, zero to 36.

FIGURE C-3

3-D Matrix



C. Since the National Resource Evaluation Center at present uses UNIVAC equipment, the AE III output tapes which serve as the basic data source are in UNIVAC format; therefore, the program procedure is related to the UNIVAC 1105 at Chapel Hill to maintain compatibility. The Chapel Hill machine configuration is:

8000 + words of core memory

16000 words drum A

16000 words drum B

Five magnetic tape units.

The machine element assignments are then:

1. 2000 + words of core for the program.
2. 6000 words of core as input area.
3. 7200 words of drum A as summing matrix storage for area summary.
4. 7200 words of drum B as state summing matrix.
5. 7200 words of drum B region summing matrix.
6. Tape I as basic data input from Attack Environment III
7. Tape II as output for area summary.
8. Tape III as output for state summary.
9. Tape IV as output for the region summary.

A representation of the computer storage assignment and information flow is given in Figure C-4; and to illustrate the program steps required, a preliminary general block diagram is presented in Figure C-5. An explanation of the flow diagram symbols in Figures C-4 and C-5 is given in Annex 1.

FIGURE C-4

Data Flow

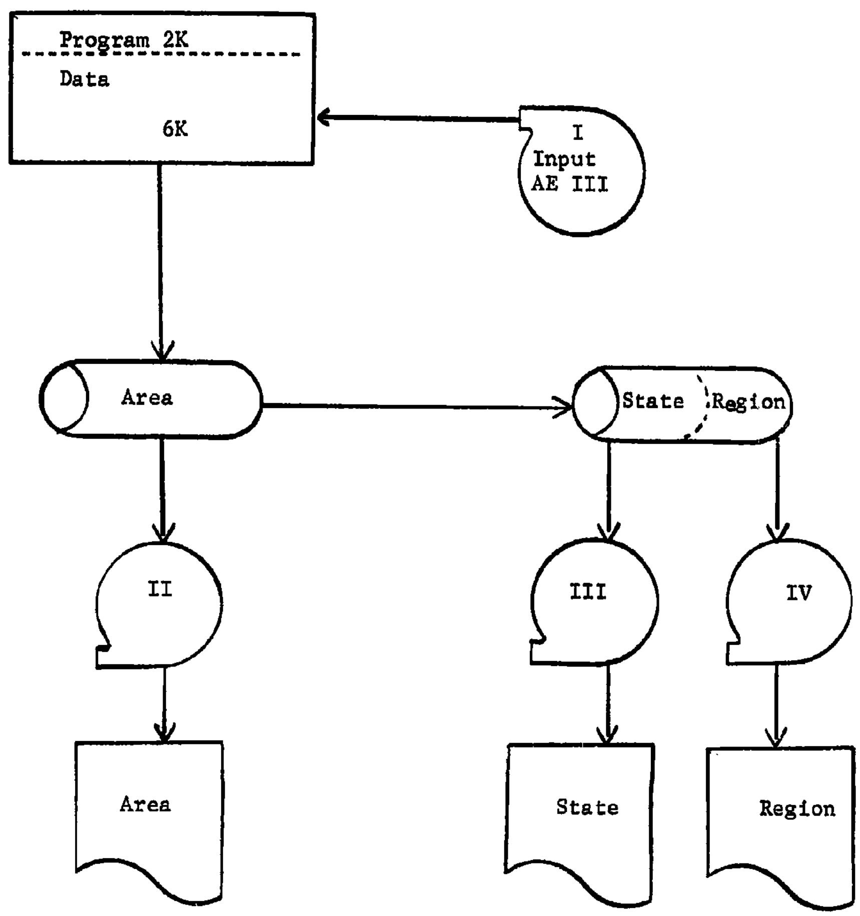


FIGURE C-5

<u>Preliminary Block Diagram</u>

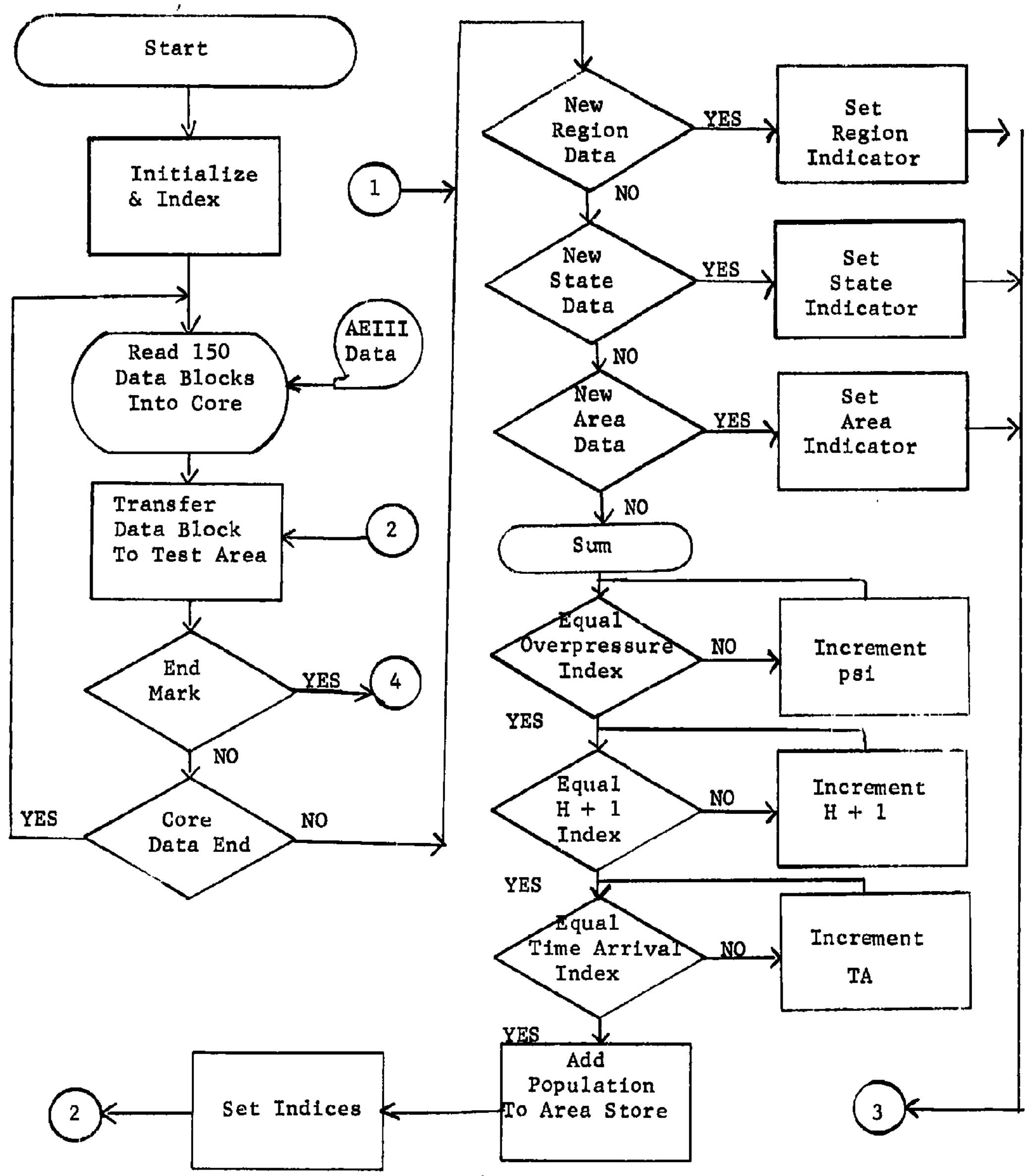
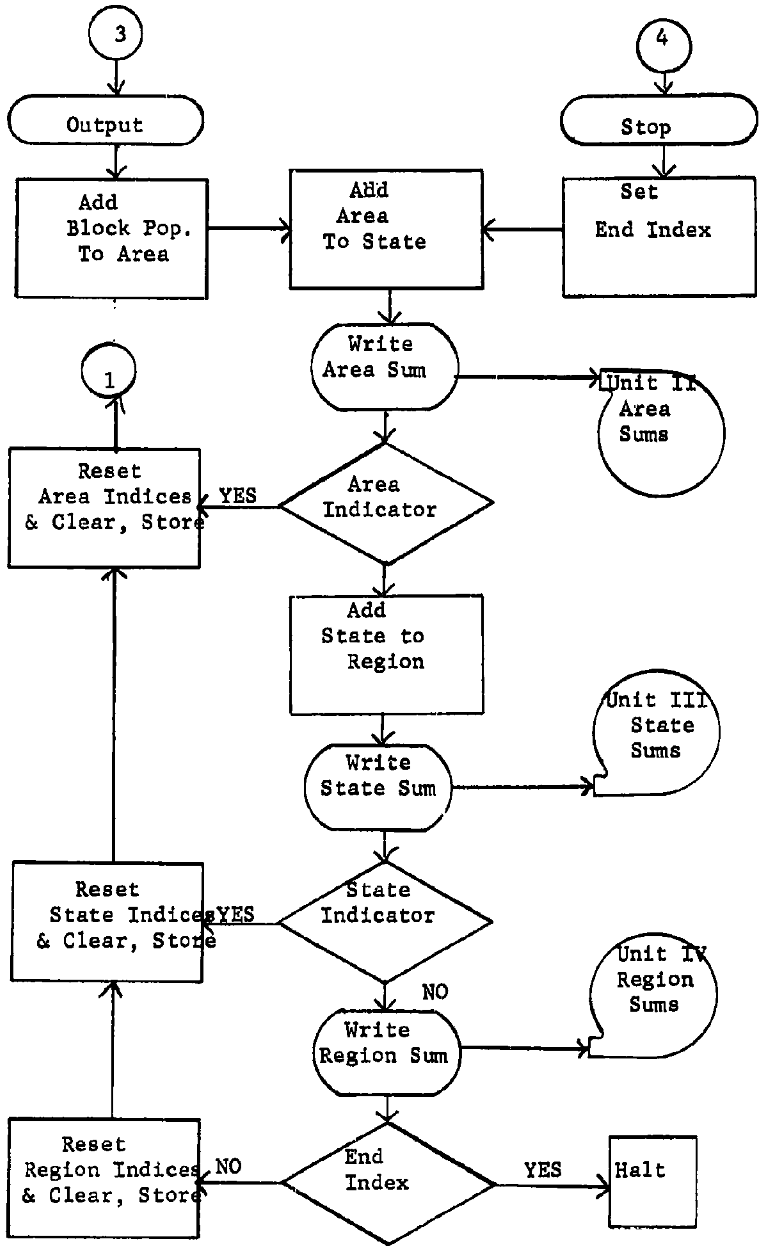


FIGURE C-5 (Continued)

Preliminary Block Diagram



III. SUMMARY

The preceding paragraphs establish a definitive procedure for producing summary documents from AE III output data. These reference documents are:

A. An area summary of people subjected to the different levels of overpressure, radiation intensity and time of arrival.

B. A state summary - Same as A.

C. A region summary - Same as A.

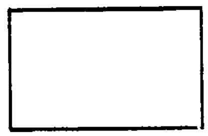
The cost associated with producing the summaries is now primarily in machine coding and machine running time.

IV. CONCLUSIONS

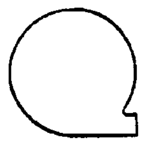
The three dimensional summary program can be accomplished as outlined and the product would serve a useful purpose. A moderate to high level of effort would be required because the AE III output tapes are in UNIVAC code; thus, symbolic programming for the 1105 is required. However, if future attack environments are run on the CDC 3600 being installed at NREC, the tape output will be in IBM 729 format. The program could then be coded in FORTRAN for a CDC 1604 or IBM 7090 at 35% of the programming and running costs. The program, once developed, could be given to NREC to run, or independent processing arrangements can be made by OCD Research Division.

Annex 1

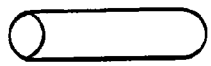
Explanation of Flow Chart Symbols



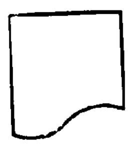
Computer Core Computation Process



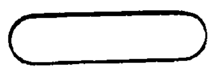
Magnetic Tape Unit



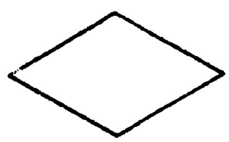
Magnetic Drum Unit



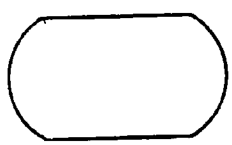
Typed Results - Documents



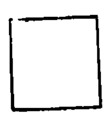
Name of a Computational Procedure



Decision or Compare Action



Output Action



End of Program

Appendix D

<u>A Feasibility Study of a Mathematical Model for Relating Population to Shelter Space</u>

This Appendix was originally submitted to OCD as Research Memorandum RM 82-4,* except for minor editorial changes.

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*H. R. Sink. <u>A Feasibility Study of a Mathematical Model for Relating Population to Shelter Space</u>. Research Memorandum RM 82-4. Durham, North Carolina: Research Triangle Institute, Operations Research Division, 26 November 1962.

Appendix D

A Feasibility Study of a Mathematical Model for Relating Population to Shelter Space

I. SUMMARY

It has been proposed by Rogers of SRI that the distribution of people in fallout shelters in a city can be analytically approximated by a procedure which he has prepared (Reference D-b). Such a procedure would reduce the difficulty of determining fallout casualties in vulnerability analyses. The procedure was derived prior to the National Fallout Shelter Survey (NFSS) and he has had no opportunity to fit the analytical model to these data.

This appendix reports an evaluation of the Rogers model of shelter distribution using NFSS data for Durham, N. C. It was found that the assumptions made by Rogers concerning shelter distribution and PF distribution are not applicable for Durham, and it is predicted that the assumption will be inaccurate for most cities.

An alternative form for the analytical expression of shelter distribution is proposed. However, neither this nor the Rogers model adequately represents the radial distribution of shelter spaces in Durham, N. C.; although there may be many cities where the fit is adequate. More important, neither the Rogers method, nor the alternative, express acceptable distributions of <u>people in shelter</u>, since they do not adequately account for movement-to-shelter.

II. INTRODUCTION

The availability of NFSS data makes possible this examination of an analytical relationship between fallout shelter spaces and population. Two distinct

mathematical models for the relationship are considered in order to compare actual data with some theoretical data. The population distribution for MODEL A is derived from actual population data obtained in a block by block analysis of Durham. A least squares exponential fit to the data is obtained. The population distribution for MODEL B is based on a circular normal distribution of population about a city population center, and also requires that the standard deviation of population density be a function of total city population. The model curve was derived by Weiss (Reference D-a) in a study of Standard Metropolitan Statistical Areas. Shelter distributions for both numerical models (MODEL A and MODEL B) were formulated from two assumptions similar to those proposed by Rogers (See Reference D-b). The assumptions are:

ASSUMPTION 1: The number of shelter spaces available per unit area is proportional to the number of people in the area.

ASSUMPTION 2: The average shelter at the center of a city has a very high protection factor; the protection factor decreases with distance from the center until a minimum PF is approached at very great distance.

The following steps are taken in an attempt to establish the validity of ASSUMPTION 1 and ASSUMPTION 2 for MODEL A and/or MODEL B:

1. The population distribution is expressed analytically in order to establish a relationship between population and shelter space.
2. A graphic representation of cumulative population and shelter space distributions is made for Durham (See Figures D-1 and D-4).
3. Since ASSUMPTION 2 relates shelters to protection afforded, an expression is derived for shelter distribution as a function of

protection factor where wall thickness is taken as the measure of protection afforded (protection factor).

4. A graph of average protection factor versus distance is drawn for Durham (See Figure D-5).

5. Casualty estimates are made based on the shelter space distribution for Durham (See Figure D-2).

III. ANALYTIC EXPRESSIONS USED TO DESCRIBE POPULATION, SHELTER SPACES, AND CASUALTY ESTIMATES

In this section the general model suggested by Rogers is described, followed by a description of MODEL A and MODEL B for Durham. Derivations of the mathematical equations are found in section VII.

A. Population Distribution

1. The center of gravity (hereafter called c.g.) of population for Durham is approximated from the 1960 Census data. The method for the approximation is described in section VII.

2. The cumulative population distribution function, $P(r)$, at any radial distance r from the population center is expressed as,

$$P(r) = 2\pi\rho_o\sigma^2 \, [1.0 - \exp(-r^2/2\sigma^2)] \quad , \qquad (1)$$

and the population density at any point in the city is assumed to have the form

$$\rho_p = \rho_o \cdot \exp(-r^2/2\sigma^2) \quad , \qquad (2)$$

where ρ_o and σ are constants (described in Section VII) and r is the radial distance (in miles) from the c.g. of population.

B. The Relationship Between Population and Shelter Space

From ASSUMPTION 1 and equation (2), the shelter density is

$$\rho_s = K \cdot \rho_o \cdot \exp(-r^2/2\sigma^2) , \tag{3}$$

and the number of shelter spaces, s, at any radial distance r from the population c.g. is,

$$s(r) = 2\pi\rho_o\sigma^2 K \left[1.0 - \exp(-r^2/2\sigma^2) \right] \tag{4}$$

where ρ_o and σ are the same constants which appear in equation (1), and

$$K = \frac{\text{total number shelter spaces}}{\text{total population}} .$$

C. Shelter Distribution as a Function of Protection Factor

1. The minimum protection factor $(PF)_m$ is taken as the minimum protection factor used in the NFSS. The NFSS does not include information on shelters with protection factors less than 20. Consequently, all shelters with a protection factor less than 20 are excluded.
2. The shelter frequency function, f(PF), is

$$f(PF) = 2\pi\rho_o\sigma^2 \, (K) \, \exp[-(a^2/2\sigma^2)(\ln[PF/(PF)_m])^{-2}] , \tag{6}$$

where "a" is a constant which relates the radial distance (from the population c.g.) to the minimum protection factor. Rogers hypothesized that "a" is a function only of the geographic area in which the city is located.

D. Development of the Numerical Models

1. In the analysis of Durham, two mathematical models are developed, MODEL A and MODEL B. As mentioned earlier (See INTRODUCTION), MODEL A is based on a least squares fit to the actual data and MODEL B is based on theoretical data.

2. The population density, ρ_s, and the cumulative population distribution function, $P(r)$, at a distance r from the population c.g. is found by a substitution of the appropriate ρ_o and σ into equations (1) and (2).

   (a) For MODEL A, the least squares fit to the data,

   $\rho_o = 7960,$

   $\sigma = 1.31.$

   (b) For MODEL B, based on the Weiss model

   $\rho_o = 15081,$

   $\sigma = 0.924.$

   A graphical representation of $P(r)$ for models A and B is shown in Figure D-1 together with a census data curve, which was plotted from actual census data.

3. From the NFSS, the total number of shelter spaces and the minimum protection factor, $(PF)_m$, are 104,535 and 20 respectively, and the total population is 80,500 (from Census data, Figure D-1). The shelter frequency function $f(PF)$, as a function of protection factor is found by substitution of the following values into equation (6):

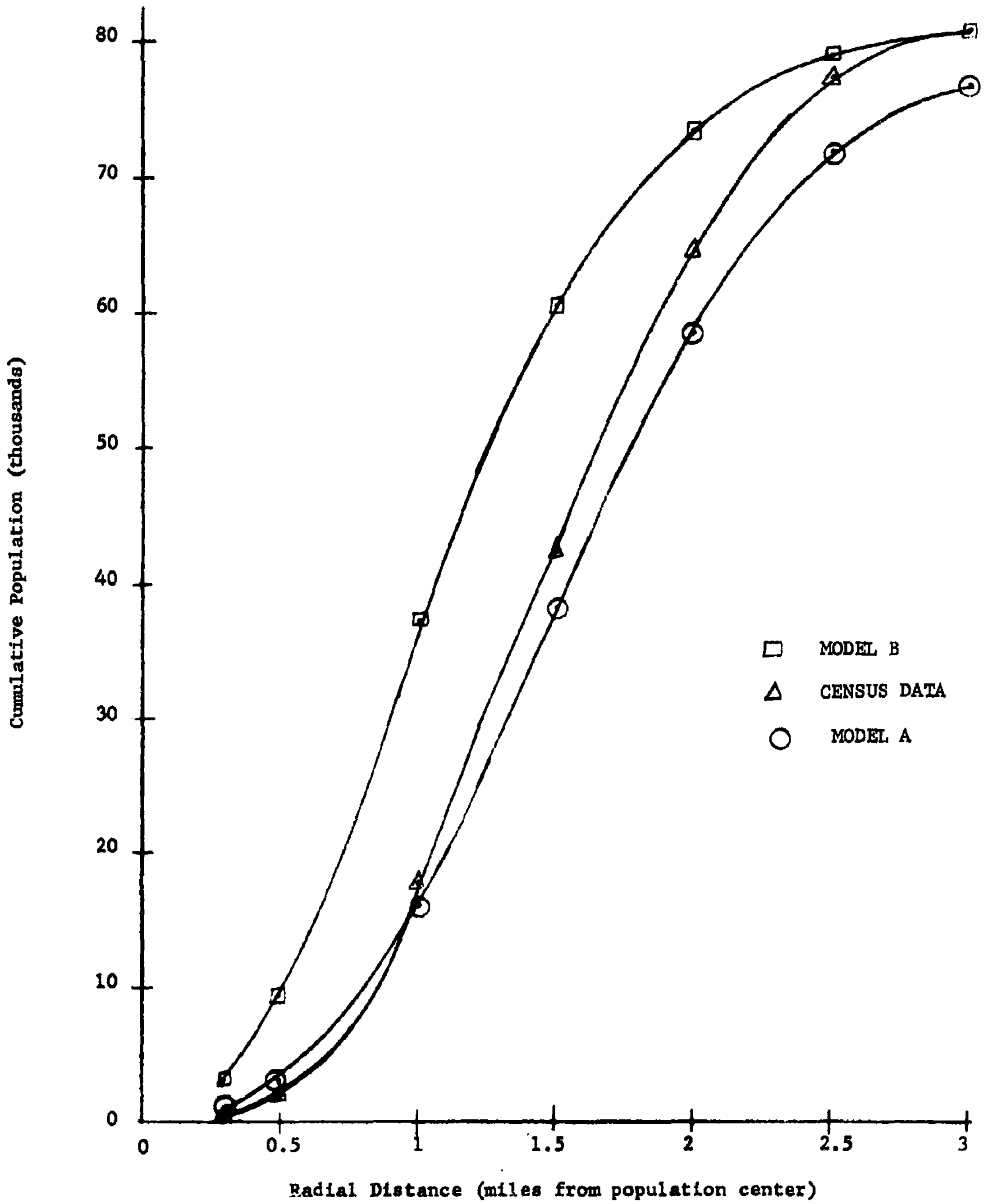
   (a) For MODEL A,

   $\rho_o = 7960,$

   $\sigma = 1.31.$

FIGURE D-1

Population as a Function of Radial Distance
From the Population Center for Durham, N.C.



(b) For MODEL B,

ρ_o = 15081,

σ = 0.924,

a = 1.15 .

E. Casualty Estimates Based on the Fallout Shelter Models and the NFSS

1. Simplified casualty estimates are made in order to determine the effectiveness of shelter spaces. In the analysis of Durham, several H + 1 intensities are applied to the city, and casualty estimates are made, assuming the following conditions:

   (a) Everyone enters the best available shelter before the arrival of fallout and remains there indefinitely.

   (b) Arrival time of fallout is one hour.

   (c) The maximum unit dose rate multiplier (DRM) for an arrival time of one hour is 2.94, occurring at 96 hours (Reference D-b) (H + 1 intensity x DRM = ERD_{max}).

   (d) The H + 1 intensity is uniformly distributed over the city.

2. A plot of the fraction of casualties as a function of ERD, given in Reference D-c, is used as the casualty function. The independent variable DOSE is a function of dose rate (H + 1 intensity), protection factor, and the shelter distribution function, as described in Section VII.

3. The prediction of casualties as a function of H + 1 intensity for Durham is given in Figure D-2. "Casualties" excludes fatalities.

IV. RESULTS

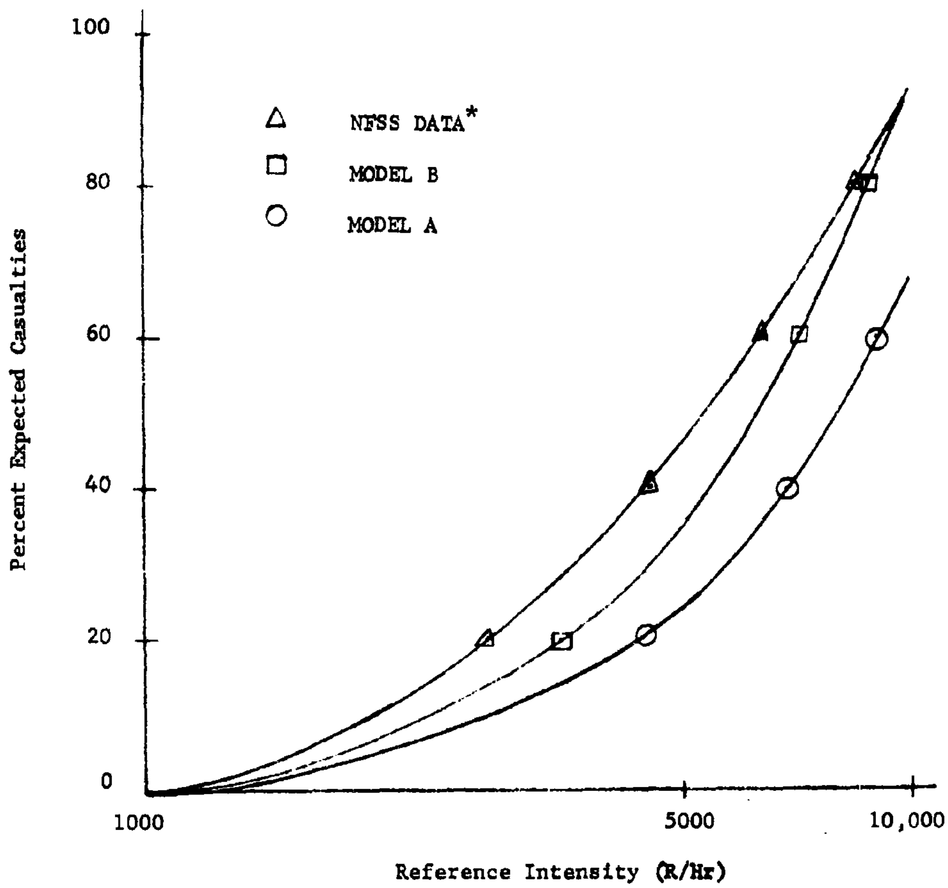
A. Population Distribution

As can be seen in Figure D-1, either model A or B appears adequate to describe

FIGURE D-2

Expected Casualties as a Function of the Intensity at H+1

Using three methods for predicting the distribution of people of Durham, N. C. in fallout shelter



* Reference D-f

the population distribution in Durham. Although MODEL A, which is a "least squares" exponential fit to 1960 Census data, agrees more closely with the actual cumulative population distribution, the procedure for calculating the equation constants is quite laborious, and for rough approximations MODEL B is more convenient. The constant, σ , which describes standard deviation of population (See Figure D-3) for MODEL B is based on the 1950 Census data; a more accurate prediction might be obtained from the 1960 Census report.

B. Shelter Distribution

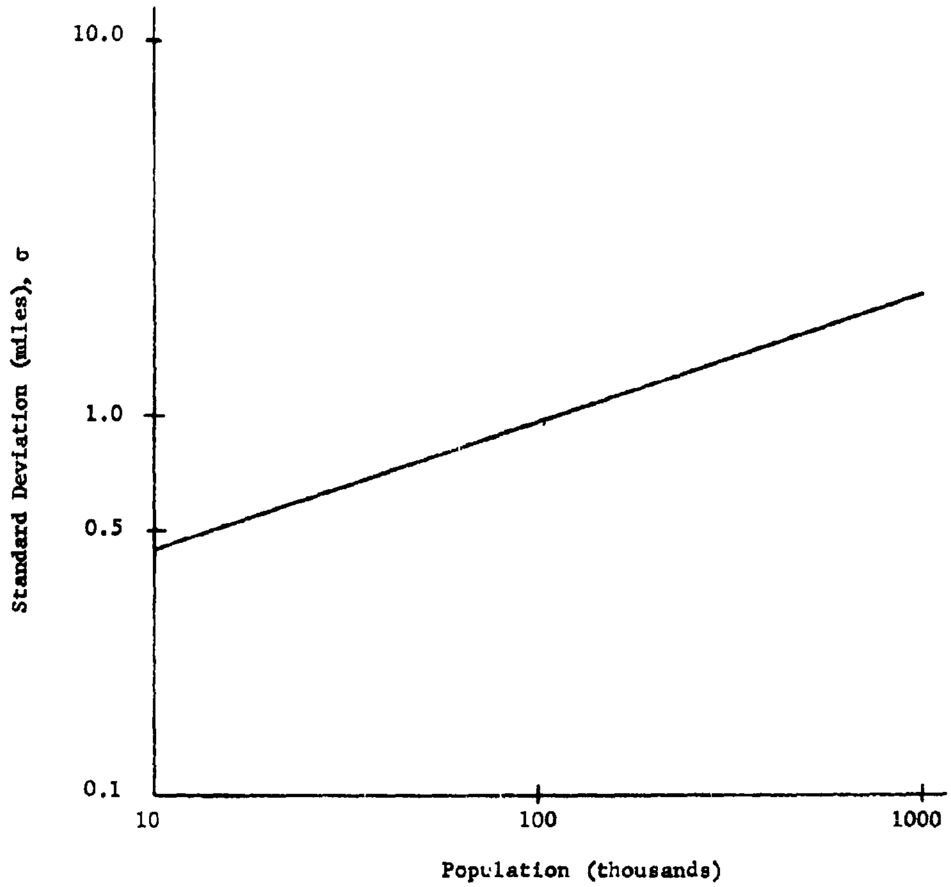
The assumption that shelter density is proportional to population density fails when tested with NFSS data. The coordinates of each shelter were found by plotting the shelters on an overlay of the city and measuring the radial distance from the population center to the coordinates. These data were plotted and compared with shelter density derived using models A and B. From Figure D-4 one can see graphically the magnitude of error. However, a knowledge of the layout of Durham is necessary in order to explain the form of this distribution. For instance, the curve describing NFSS data has a "hump" located approximately one mile from the population center and a second "hump" located approximately two miles from the population center; these are the locations of the East and West campuses of Duke University. In addition, North Carolina College is located at approximately the same radial distance from the population center as the Duke West campus. It is quite apparent that Durham cannot be described precisely by a simple shelter distribution which ignores the unusual assembly of shelters situated away from the population center.

C. Protection Factor Distribution

The assumption that protection factor decreases with increase in distance from the population center proved invalid for Durham; this can be seen in Figure D-5.

FIGURE D-3

<u>Variation of σ with Population of Metropolitan Areas</u>

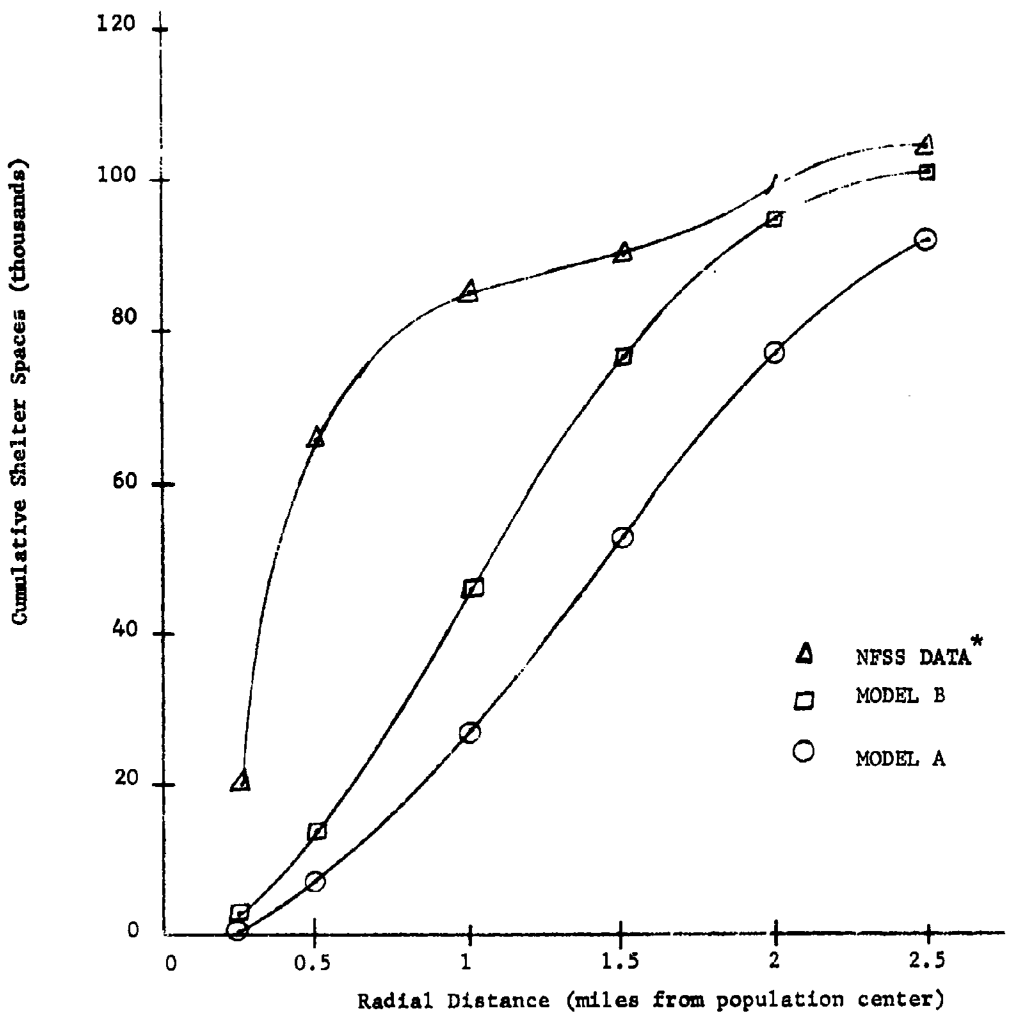


Source: See Reference D-b, Section II

FIGURE D-4

Shelter Spaces as a Function of Radical Distances

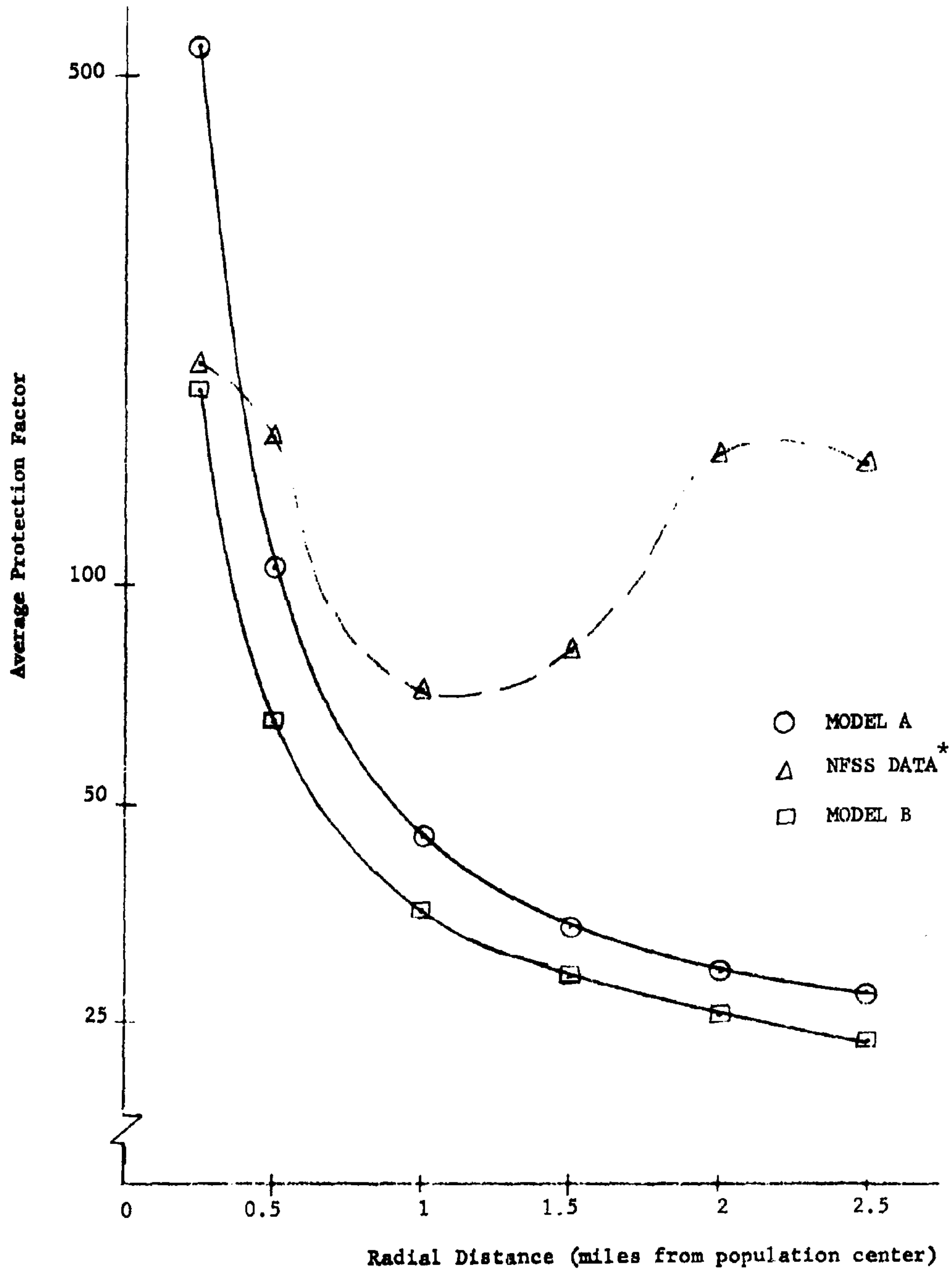
From City Center for Durham, N. C.



* Reference D-f

Average Protection Factor as a Function of Radial Distance

From City Center for Durham, N. C.



*Reference D-f

The large university shelters are quite prominent near the outskirts of the city. The high protection factor observed near the center of the city for MODEL A stems from the fact that the shelter distribution has a large number of high PF shelters, and MODEL A assumes that these shelters are situated near the center of the city. MODEL B, which forces a fit to a specified form of distribution function, more closely fits the data at the city center.

V. A PROPOSED ALTERNATIVE

A functional form that appears promising to approximate shelter space distribution is the following:

$$s(r) = Hr^{-k} \qquad (7)$$

where H and k are constants and r is the radial distance from the population center. Distributions of this type were derived for Durham and Atlanta (Figure D-6).

VI. CONCLUSIONS

The two assumptions which this analysis has been designed to test, did not prove accurate for Durham, N. C. Although generally applicable conclusions can not be derived from a single sample analysis, it is true that the distribution of shelter spaces is not proportional to the distribution of the population in all cities.

Also, it is extremely difficult to relate the protection factor of a shelter space to distance and again, not all cities can be described simply.

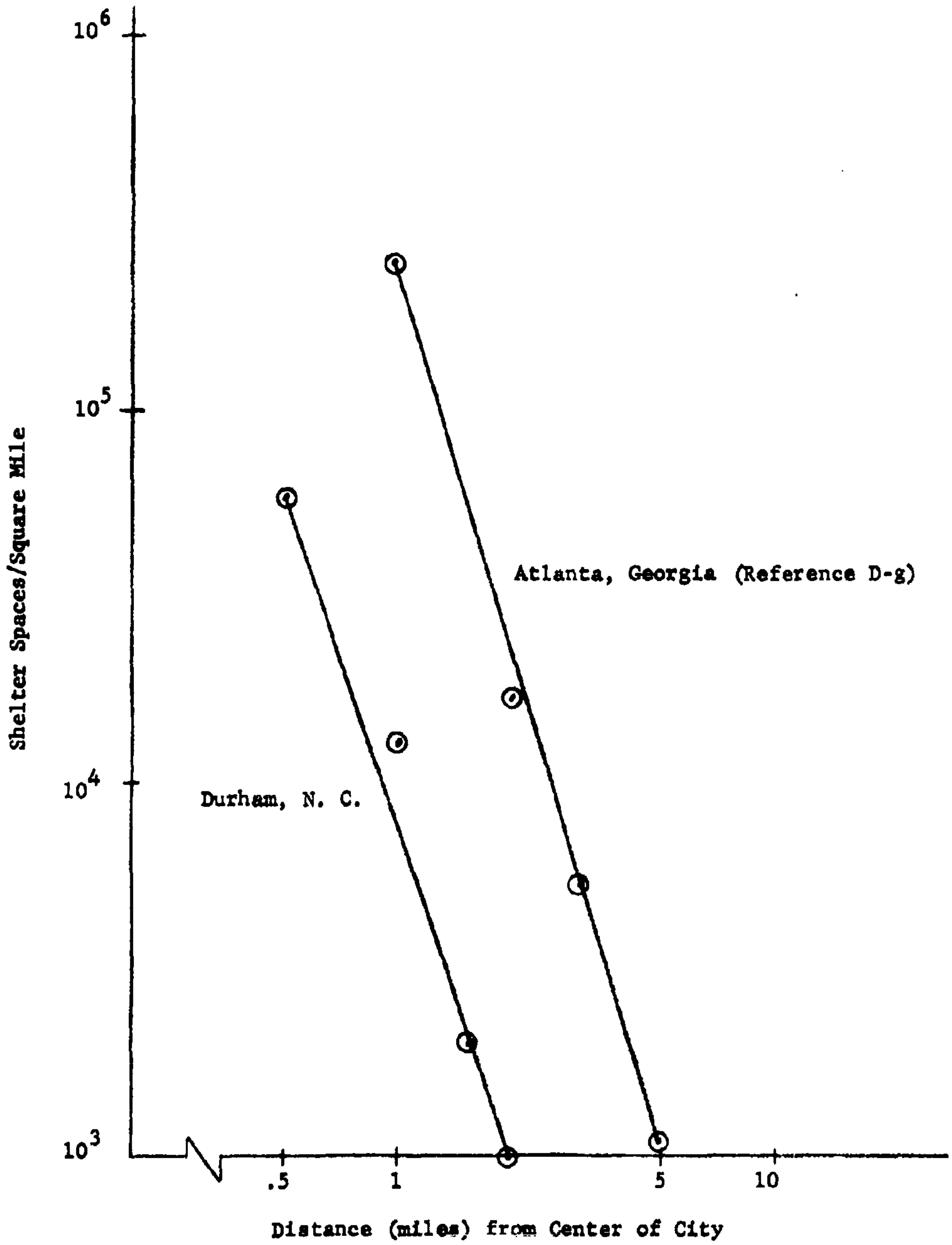
As in this analysis, there is no way of obtaining *a priori*, certain parameters, such as "a", which are necessary to the calculations.

The "radial city" concept is still regarded as interesting and potentially useful, but without further research, little use can be made of such a model.

FIGURE D-6

Shelter Space Density as a Function of Radial Distance

From the Population Center



VII. DERIVATION OF MATHEMATICAL EXPRESSIONS

A. Determination of the Population Center of Gravity

1. The city is inscribed in a rectangle, M.
2. M is subdivided into N rectangles, each of unit area
3. The population, p_i, for each unit is found by making a block by block analysis of census data.
4. The centroid of population is approximated visually for each rectangle.
5. The rectangular coordinates of each centroid are found relative to the geometric center of M, i.e. (x_i, y_i) $i = 1, \ldots, N$.
6. The coordinates $\bar{x}$ and $\bar{y}$ of the population center of gravity are equal to the sum of the corresponding moments of the unit rectangles.

$\bar{x} = \frac{\sum_{i=1}^{N} x_i\, p_i}{P}$ $\bar{y} = \frac{\sum_{i=1}^{N} y_i\, p_i}{P}$, where P represents total population.

B. Radial Population Distribution Function*

1. A study made by Sherratt (Reference D-d) indicates that population density for any city can be expressed in terms of distance, r, from the center of the city by

$$\rho = \rho_o \exp(-r^2/2\sigma^2) , \tag{8}$$

where ρ_o and σ are constants.

$$dP(r) = \rho \cdot dA.$$

where dA is the element of area.

$$dA = 2\pi r(dr) . \tag{9}$$

* The derivation shown in Section B - D are essentially those of Reference D-b.

The cumulative population distribution function, $P(r)$ is then given by

$$P(r) = 2\pi\rho_o \int_o^r r \exp(-r^2/2\sigma^2)\, dr, \tag{10}$$

$$= 2\pi\rho_o\sigma^2[1.0 - \exp(-r^2/2\sigma^2)] . \tag{11}$$

3. Determination of ρ_o and σ

(a) MODEL A: A transformation of equation (8) gives

$$\ln \rho = \ln \rho_o - r^2/2\sigma^2 \tag{12}$$

Density samples are taken at various radii from the population center, and a least squares curve evaluation is used to calculate ρ_o and σ .

(b) Weiss (Reference D-a) has plotted the variation of σ with population of the Standard Metropolitan Areas (Figure D-3). Equation (11) may be reduced to

$$P = 2\pi\rho_o\sigma^2 \quad , \tag{13}$$

for very large values of r. A large value for r will include essentially the total population and from equation (13)

$$\rho_o = \frac{\text{Total Population}}{2\pi\sigma^2} \quad . \tag{14}$$

C. Shelter Space as a Function of Population

1. ASSUMPTION 2 of the INTRODUCTION shows the protection afforded by a shelter as a function of the distance from the population center. The following definition is given for protection afforded:

(a) From the laws of physics, the intensity, I, of a beam of gamma rays

emerging from a slab of material is a function of the incident intensity, I_o, the thickness of the material x, and the linear absorption coefficient u.

$$I = I_o \exp(-ux) \ . \tag{15}$$

(b) If in lieu of u we substitute u' which takes into account multiple scattering of gamma rays and the geometry of the fallout field, then

$$I = I_o \exp(-u'x) \ . \tag{16}$$

(c) By definition, the protection factor PF is

$$PF = I_o/I = \exp(-u'x) \ . \tag{17}$$

(d) ASSUMPTION 2, stated analytically, is

$$u'x = \ln(PF) = (a/r) + b \ , \tag{18}$$

where "a" and "b" are constants. As r gets very large, then PF approaches a minimum value and

$$u'x = \ln(PF)_m = b \ , \quad (r \longrightarrow \infty) \tag{19}$$

$$(a/r) = \ln[PF/(PF)_m \ ], \tag{20}$$

$$r = \frac{a}{\ln[PF/(PF)_m]} \tag{21}$$

where $(PF)_m$ is the minimum protection factor.

(e) ASSUMPTION 1 stated analytically is

$$\rho_s = K\ \rho_p\ ,$$

$$\rho_s = K\ \rho_o\ \exp(-r^2/2\sigma^2)\ . \tag{22}$$

(f) To find the total number of shelters, S, for a given PF, a ring of radius r and width dr is considered to encircle the population c.g. Then the number of shelter spaces in this annulus at a distance r is

$$s(r) = 2\pi\,\rho_s r(dr)\ , \tag{23}$$

and the cumulative number of spaces out to radius r is

$$S(r) = 2\pi\,\rho_o K\int_o^r [r\ \exp(-r^2/2\sigma^2)]\ \ dr\ , \tag{24}$$

or

$$S(r) = 2\pi\,\rho_o K\sigma^2[1.0 - \exp(-r^2/2\ \ ^2)]\ . \tag{25}$$

(g) K is selected such that S is a maximum when $r \longrightarrow \infty$. S(r) can now be considered the cumulative distribution function of shelter spaces for the variable r. Accordingly

$$S_{max} = 2\pi\rho_o K\sigma^2 \tag{26}$$

and

$$K = \frac{S_{max}}{2\pi\rho_o\sigma^2} = \frac{\text{Total Shelter Spaces}}{\text{Total Population}}\ . \tag{27}$$

(h) The cumulative distribution of shelter spaces in terms of PF, call it F(PF), can be obtained by substituting r from equation (21) into equation (25)

$$F(PF) = 2\pi\rho_o K\sigma^2[1.0 - \exp\ (-a^2/2\sigma^2)(\ln PF/(PF)_m)^{-2}\ ]\ .$$

The fraction of shelter spaces in terms of PF is thus

$$f(PF) = 2\pi\rho_o K\sigma^2\ \exp[(-a^2/2\sigma^2)(\ln PF/(PF)_m)^{-2}\ ] \tag{28}$$

where "a" is determined as follows:

$$\ln[f(PF)] = \ln[2\pi\rho_o\sigma^2 K] - (a^2/2\sigma^2)[\ln PF/(PF)_m]^{-2} , \tag{29}$$

$$Q = [\ln PF/(PF)_m]^2$$

$$(-a^2/2\sigma^2) = \frac{1}{Z}\sum_{i=(PF)_m}^{PF} [\ln f(PF)_i - \ln(2\pi\rho_o\sigma^2 K)] \cdot Q \quad . \tag{30}$$

F(PF) is found from the NFSS data where "Z" is the number of PF categories.

D. Casualty Estimates

1. ERD_{max} = R(2.94)/PF for effective arrival time of 1 hour where R is the H + 1 intensity.

2. Casualty rate is a function of ERD_{max} (Reference D-e).

3. Percent Casualties = $\sum_{i=(PF)_m}^{PF} [(\text{Casualty rate})_i \; F(PF)_i]$.

VIII. APPENDIX D REFERENCES

D-a. Herbert Weiss. The Distribution of Urban Population and an Application to a Servicing Problem. Journal of the Operations Research Society of America, Volume 9, November-December, 1961. pp 860-874.

D-b. Jack Rogers. A Theoretical Study of Existing Fallout Shelters. Menlo Park, California: Stanford Research Institute, March 1962.

D-c. Joseph Coker. Nuclear Attack Hazard and Resource Evaluation Models. Washington: Executive Office of the President, Office of Emergency Planning, 1961.

D-d. G. G. Sherratt. A Model for General Urban Growth. Management Sciences, Models and Techniques, Pergamon Press, Volume 2, 147, 1960.

D-e. Herbert E. Campbell. The Variation of Casualties with the Method of Representing Shelter Data and the Distribution of People in Shelter. RM-82-3, Durham, N. C.: Research Triangle Institute, Operations Research Division, September 10, 1962.

D-f. Research Triangle Institute. A Fallout Shelter Survey of Durham, N. C., performed by RTI personnel in a test of NFSS procedures and computer PF calculations. Results are available only as an internal memorandum report. The survey was performed under OCD Contract Number SD-96. October, 1961.

D-g. National Bureau of Standards. Phase 1 NFSS Summary A Printouts for Atlanta, Ga., Obtained from the Shelter Survey Division, Office of Civil Defense, DOD, Washington: November, 1962.

Appendix E

Distribution of Shelter Characteristics

This Appendix was originally submitted to OCD as Research Memoranda RM 83-1 and RM 83-2,* except for minor editorial changes.

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* H. C. Sweeny. Distribution of Shelter Characteristics: I. Reduction of National Fallout Shelter Survey Data. Research Memorandum RM 83-1. Durham, North Carolina: Research Triangle Institute, Operations Research Division, 26 November 1962.

H. C. Sweeny. Distribution of Shelter Characteristics: II. An Application of Reduced National Fallout Shelter Survey Data. Research Memorandum RM 83-2. Durham, North Carolina: Research Triangle Institute, Operations Research Division, 27 November 1962.

Appendix E

Distribution of Shelter Characteristics

I. INTRODUCTION

The object of OCD Project 4521A, "Data Base on Shelter Needs," is to establish the procedures and requisite steps necessary to use the National Fallout Shelter Survey (NFSS) data in evaluating the need for additional shelter spaces by standard location. This analysis will require the handling of considerable data. Previous investigations of civil defense operations were often hampered by the paucity of data in many areas of investigation which in some instances led to the use of questionable assumptions. Data are now available in most areas of concern in the National Fallout Shelter Survey (NFSS); however, we are now confronted with the problem of having "too much" data to conveniently handle for analysis.

The results of the NFSS would considerably enhance current and future civil defense operations research efforts, if the bulk of these data could be reduced to more manageable proportions. Accordingly, in this appendix we will inquire into the characteristics of the data which are to be reduced and into the requirements for data reduction. It is not the object of this research to study data reduction as an end in itself, but only the reduction of those data which it is believed may be generally applied in the prosecution of OCD Project 4521A.

The examples used throughout this appendix were obtained from NFSS data on Census Tracts 25 and 26 in Houston, Texas and from a pilot study of shelter surveys by the Research Triangle Institute of Durham, N. C., the results of which are given in Reference E-a and E-b.

II. BACKGROUND AND ASSUMPTIONS

Let $r_i (i = 1, 2, 3, \ldots, M)$ be the reduction factor* associated with the ith shelter in some geographic area, and let n_i denote the number of spaces in the ith shelter. The total number of spaces in the area is $N = n_1 + n_2 + \ldots + n_M$, i.e., $N = \sum_{i=1}^{M} n_i$.

We may consider that the basic data for a given geographic area consists of M sets of data--one set for each shelter--of the form:

$$(r_i = \text{reduction factor},\ n_i = \text{number of spaces}) .$$

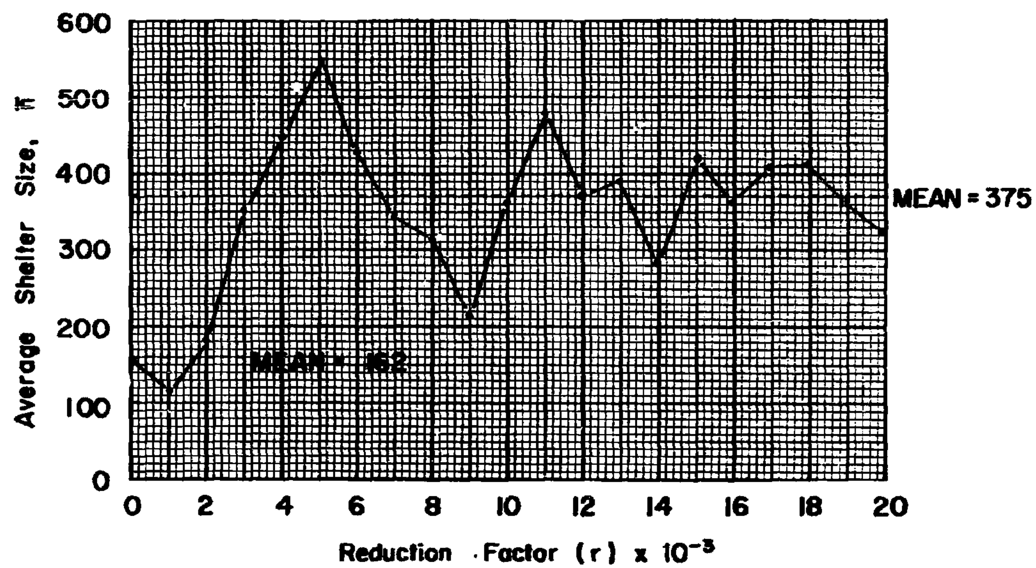
Correlation should be evident between r and n for a number of reasons, the principal one being that for basements--which usually have a very low value of r--the value of n is obtained by using a standard of 500 cu. ft. per space; whereas for upper floors--which usually have a higher value of r--the standard has been set at 10 sq. ft. per space. Accordingly, a basement with a 10-ft. ceiling would use 50 sq. feet of floor area per space, thereby reducing n by a factor of 5.

Shelter size is an important consideration in those areas of operations research concerned with shelter habitability. These areas cover many diverse considerations; _i.e._, logistic support, number of trained shelter managers, psychological and sociological aspects of shelter life, _etc_. Thus, n, the shelter size in terms of the number of spaces available must be considered. Its effect is shown in Figure E-1 which is a plot of the average value of n for shelters with various reduction factors. For $0 \leq r \leq .002$ the average value of n is 162; for $.002 < r \leq .020$ the average value of n is 375. (A value of $r = 0.000$ may be interpreted as $0.000 \leq r < 0.0005$.)

*The "reduction factor" is the inverse of the "protection factor," the latter being equal to the ratio of the amount of dose received without protective action to the amount received with protective action.

FIGURE E-1

AVERAGE SHELTER SIZE FOR
VARIOUS REDUCTION FACTORS
Census Tract 25, Houston, Texas



III. MATHEMATICAL MODEL

The most obvious way of representing the data is by frequency distributions, thus affording some reduction in the data volume. Examples of such distributions for Census Tract 25, Houston, Texas, are given in Table E-I for those shelters

TABLE E-I

Shelter Size Distribution

Census Tract 25, Houston, Texas

r = 0.000 through 0.001

Shelter Size n	Frequency f	Relative Frequency r.f.	Cumulative Frequency c.f.
50 - 99	25	0.391	64
100 - 149	16	0.250	39
150 - 199	10	0.156	23
200 - 249	7	0.110	13
250 - 299	2	0.031	6
300 - 349	3	0.047	4
350 - 399	1	0.015	1

with r = 0.000 through r = 0.001; and in Table E-II for those shelters with values of r from r = 0.002 through 0.010. It is possible to represent such shelter size distributions by some mathematical approximation. There is, however, one difficulty which arises from the restriction that a shelter must be able to house at least 50 persons. Thus, any density function assumed will always be truncated at n = 50. This complicates the statistical assessment of empirical distributions.

TABLE E-II

Shelter Size Distribution

Census Tract 25, Houston, Texas

$r = 0.002$ through 0.010

Shelter Size n	Frequency f	Relative Frequency r.f.	Cumulative Frequency c.f.
50 - 199	41	0.345	119
200 - 349	27	0.227	78
350 - 499	23	0.193	51
500 - 649	12	0.100	28
650 - 799	4	0.034	16
800 - 949	8	0.067	12
950 - 099	4	0.034	4

Several analytical models have been used on the survey data with varying degrees of success. Figure E-2 is a semi-logarithmic plot of the cumulative frequencies given in Table E-I (the encircled points) and Table E-II (the ensquared points). If we assume an exponential distribution, a special case of the Gamma distribution, of the form:

$$f(n) = \lambda e^{-\lambda(n - n_0)}, \quad n_0 \leq n < \infty, \tag{1}$$

with a mean:

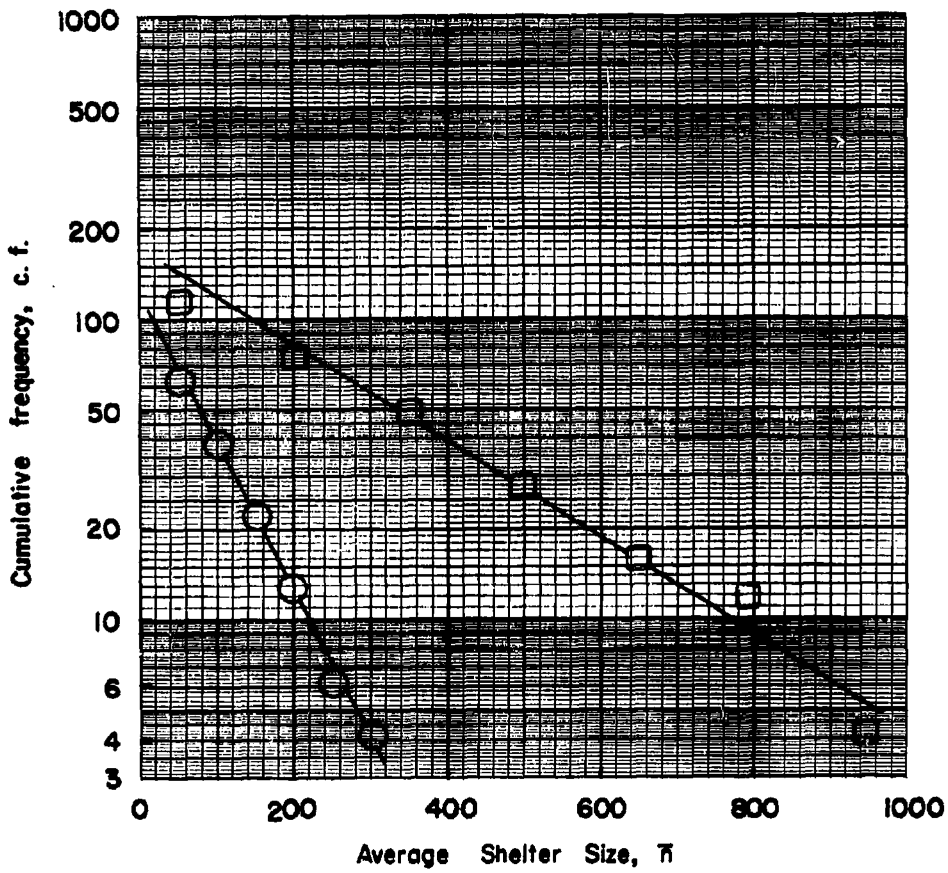
$$E(n) = \frac{1}{\lambda} + n_0 , \tag{2}$$

and a variance:

$$Var(n) = \frac{1}{\lambda^2} , \tag{3}$$

FIGURE E-2

CUMULATIVE FREQUENCY DISTRIBUTION
OF SHELTER SIZE
Census Tract 25, Houston, Texas



where n is the shelter size in terms of the number of spaces available and $n_0 = 50$ is the truncation point; then the number of shelters of size n or larger is denoted by N(n) and from equation (1) is:

$$N(n) = N(50)e^{-\lambda(n - 50)} \tag{4}$$

where N(50) is the total number of shelters with 50 or more spaces per shelter. From the data given in Table E-I we obtain N(50) = 64 and $\lambda = 10.9 \times 10^{-3}$; and from the data given in Table E-II we obtain N(50) = 119 and $\lambda = 3.19 \times 10^{-3}$. In neither case does the Chi-squared test for a fit of a distribution suggest that the assumed exponential distribution is inadequate.[1/]

IV. MODEL EXTENSIONS

Based on the assumptions made above there are several hypotheses which should be investigated. For example, it would be extremely interesting to know whether basement shelters would have the same frequency distribution as other shelters if they were completely ventilated. The shelters with reduction factors of r = 0.000 and r = 0.001 have an average size of $50 + (10.9 \times 10^{-3})^{-1} = 141.8$; for the remaining shelters we have an average size of $50 + (3.19 \times 10^{-3})^{-1} = 364$ (cf. Figure E-1). Thus, if the shelters with low reduction factors have the same distribution when ventilated, this would add (364 - 141.8)(64) = 14,200 spaces which is a 27% increase in space availability.

Let us now consider the distribution of reduction factors in a limited geographical area; these may be expressed in two ways: (1) the distribution may be on a "per shelter" basis, or (2) it may be on a "per shelter space" basis.

[1/] Among other distributions considered the log-normal distribution was the only other distribution that showed some promise of success--at least on the Durham data given in reference E-b.

It would appear that the latter is the most logical basis.

The data on Census Tract 25 in Houston was reduced by collecting the number of shelters and shelter spaces for each reduction factor. The results are given in Table E-III and the cumulative number of shelter spaces N(r) is plotted against the reduction factor r in Figure E-3. It can be seen that the major portion of the data may be represented by a straight line; the break in the curve occurs at approximately $r = 0.0025$, which is quite a low value of r. We can surmise that this is a result of the different shelter size distributions observed for low and high values of r.

The line may be represented by a cumulative distribution function of the form:

$$N(r) = N(1)r^{\alpha} \quad , \quad 0 \leq r \leq 1 \quad , \tag{5}$$

where N(1) is the intercept, α the slope parameter, and N(r) is the number of shelter spaces which have a reduction factor of at least r.

The straight line obtained in Figure E-3 is not a unique case as can be seen by Figure E-4 which presents comparable curves for Durham, N. C. (from Reference E-b), Washington, D. C., and North Carolina (the data for the latter two being obtained from NFSS summary printouts of 21 May 1962). These three cases are apparently adequately presented by a straight line. That this is <u>not</u> a general case can be seen from the data given in Figure E-5. The data were obtained from Census Tract 26, Houston, Texas, and are given in Table E-IV. The data, it appears, can be fairly approximated by two straight line segments.

TABLE E-III

Distribution of Shelters and Shelter Spaces by Reduction Factor

Census Tract 25, Houston, Texas

Reduction Factor x 10^{-3}	No. of Shelters	No. of Shelter Spaces, n	Cumulative No. of Shelters	Cumulative No. of Shelter Spaces, N(r)
0	42	6375	42	6375
1	14	1671	56	8046
2	6	1071	62	9117
3	5	1754	67	10871
4	11	4934	78	15805
5	13	7120	91	22925
6	12	5143	103	28068
7	12	4149	115	32217
8	21	6646	136	38863
9	18	3832	154	42695
10	10	3591	164	46286
11	26	12474	190	58760
12	13	4884	203	63644
13	19	7382	222	71026
14	18	5153	240	76179
15	23	9728	263	85907
16	22	7992	285	93899
17	21	8612	306	102511
18	30	12433	336	114944
19	22	8023	358	122967
20	15	4819	373	127786
21	23	7173	396	134959
22	19	7771	415	142730
23	12	5119	427	147849
24	13	3680	440	151529
25	11	3480	451	155009

FIGURE E-3

CUMULATIVE NUMBER OF SHELTER SPACES

AS A FUNCTION OF REDUCTION FACTOR

Census Tract 25, Houston, Texas

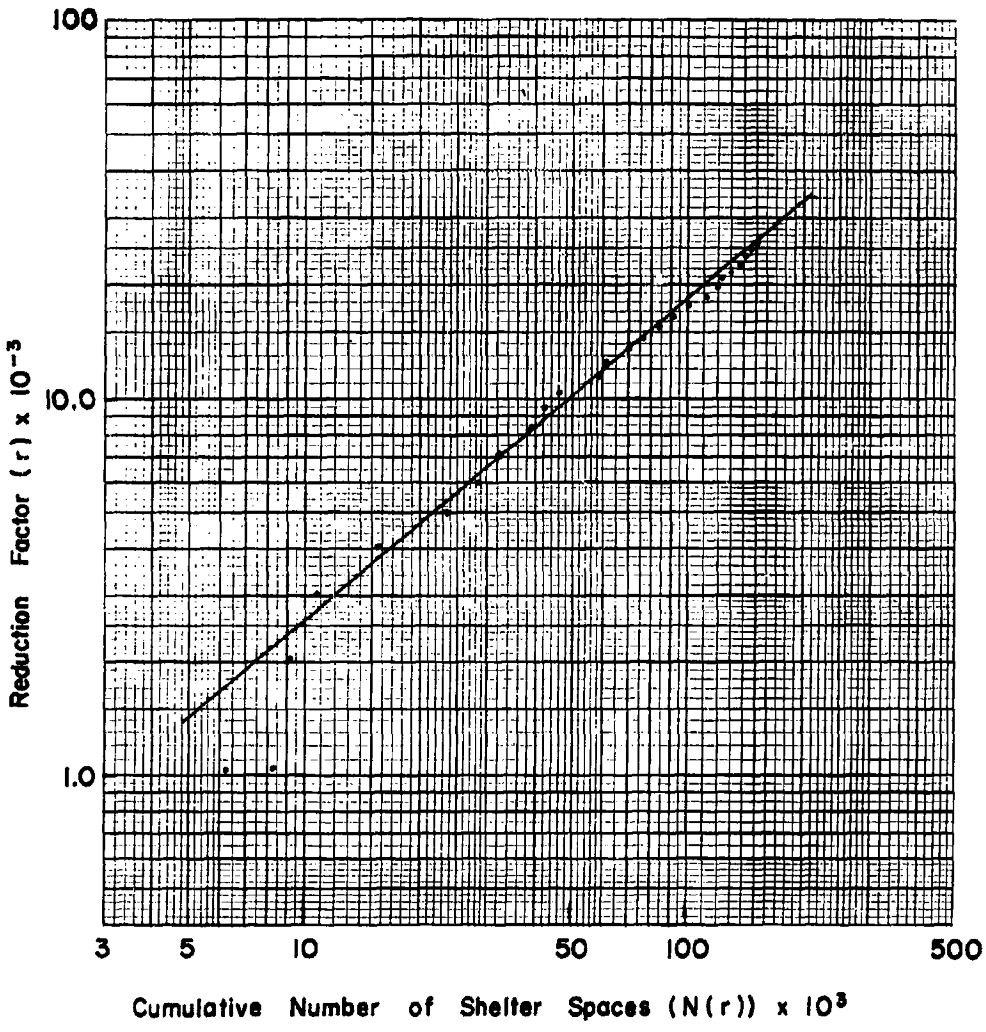


FIGURE E-4

COMPARATIVE CUMULATIVE NUMBER OF SHELTER SPACES AS A FUNCTION OF REDUCTION FACTOR

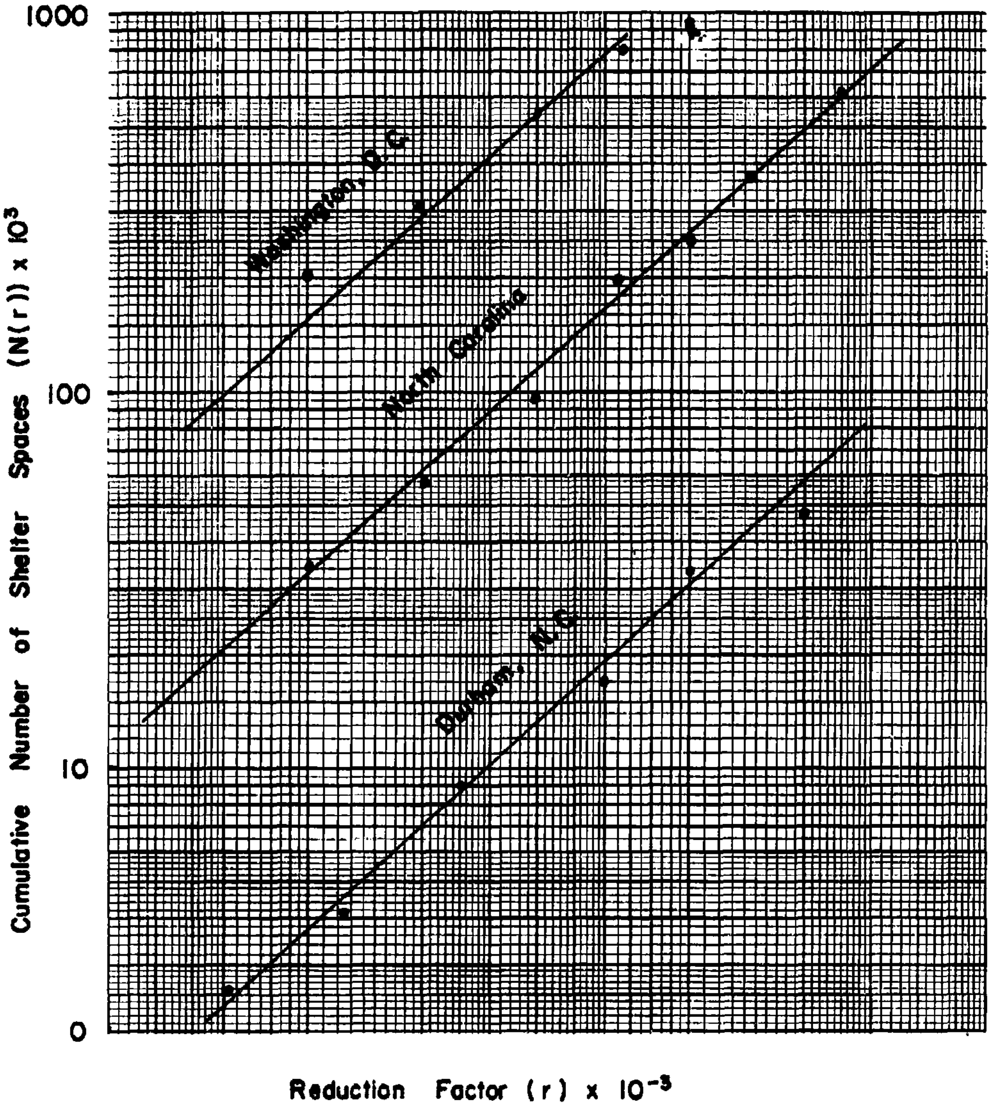
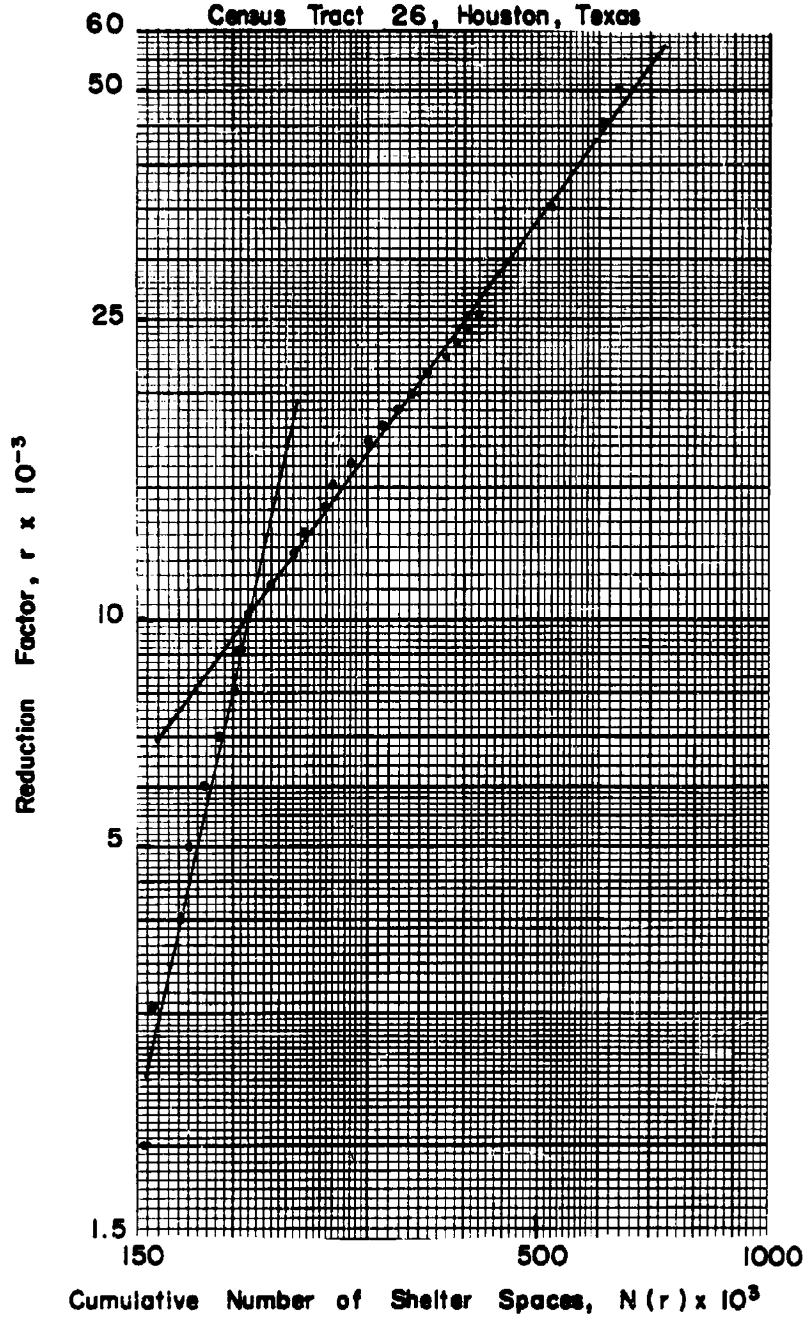


FIGURE E-5

CUMULATIVE NUMBER OF SHELTER SPACES AS A FUNCTION OF REDUCTION FACTOR*

Census Tract 26, Houston, Texas



* Complete ventilation

TABLE E-IV

Distribution of Shelters and Shelter
Spaces as a Function of Reduction Factor
Census Tract 26, Houston, Texas

Reduction factor $r \times 10^{-3}$	Volume Base		Area Base	
	No. of Shelters	No. of Shelter Spaces	No. of Shelters	No. of Shelter Spaces
0	49	20,267	57	80,540
1	76	39,507	89	125,706
2	83	64,701	100	154,925
3	85	65,016	103	156,438
4	94	77,821	112	170,701
5	99	81,410	118	174,417
6	111	89,621	130	182,926
7	121	96,789	140	190,445
8	141	104,864	162	199,305
9	152	109,226	173	203,667
10	161	113,259	182	207,938
11	183	129,343	206	224,761
12	203	144,345	227	239,938
13	218	154,157	242	249,750
14	235	166,715	260	262,359
15	250	175,495	275	271,139
16	283	191,296	308	287,192
17	308	204,929	333	300,825
18	335	218,560	360	314,737
19	355	235,087	380	331,264
20	376	247,812	401	343,989
21	406	265,007	431	361,184
22	440	285,468	465	381,645
23	458	294,640	483	390,817
24	481	310,072	506	406,249
25	506	323,254	532	419,561
26 - 35	722	425,096	749	522,120
36 - 45	879	507,035	908	604,288
46 - 50	942	541,744	971	639,093

V. AN APPLICATION OF REDUCED NATIONAL FALLOUT SHELTER SURVEY DATA

A. Introduction

In the sections which follow, the distribution of shelter sizes is used in a simplified analysis of the problem of ventilation of volume restricted spaces. The purpose is to illustrate the usefulness of summarized NFSS data with an example. It should be noted that many other questions, such as determination of optimum container size for stocking shelters, could be investigated through such distributions.

Preliminary work has indicated that values of the parameters λ and N(50) throughout the country are functions of location and city sizes; it may be possible to group similar values of λ for broad geographical areas and to relate N(50) to city size. If this is true, the use of distribution functions may drastically reduce the bulk of the NFSS data and allow rapid studies, such as the one indicated herein, to be made for broad regions without extensive numerical computation.

B. Shelter Size Distributions

Let n denote the number of spaces in a shelter (that is, the number of people which it may hold) and let r denote the reduction factor (inverse of the protection factor) associated with the shelter. It was shown earlier that quite often distribution of shelter sizes may be described by the truncated exponential law:

$$\begin{aligned} f(n|\lambda) &= 0 \qquad\qquad ; \quad 0 \leq n < 50 \\ &= \lambda e^{-\lambda(n-50)} ; \; 50 \leq n \leq \infty , \end{aligned} \tag{6}$$

where the truncation at n = 50 occurs due to the requirement that a shelter have at least 50 spaces. The parameter λ is a measure of the average shelter size E(n):

$$E(n) = 50 + \frac{1}{\lambda} . \qquad (7)$$

It was suggested further that distributions of basement shelter sizes, in which the size depends on volume, would have a different value of λ than distributions of shelter sizes based on area. Let λ_v and λ_a denote these two cases respectively. Let M_v and M_a denote the number of shelters in which the number of spaces is restricted by volume and by area, respectively. Then $M_v \cdot \left(50 + \frac{1}{\lambda_v}\right)$ is the average number of spaces which are restricted by volume and $M_a \cdot \left(50 + \frac{1}{\lambda_a}\right)$ is the average number of spaces restricted by area. The actual volume and area restrictions which have been used by OCD are 500 cu. ft. per space and 10 sq. ft. per space.

C. Modification of Shelter Ventilation

It is possible to increase the number of shelter spaces available by providing artificial ventilation for those shelters which are restricted by volume considerations. Fortunately, most of these shelters are so located (in basements, for example) that the reduction factors associated with them are quite high; thus, artificial ventilation will usually provide prime additional spaces. There are

$$M_v f(n \mid \lambda_v) dn \qquad (8)$$

shelters with sizes between (n) and (n+dn) which are restricted by volume and which may be modified. Each shelter so modified will have a volume of (500n) cubic feet and, if h is the height of the shelter, will have a floor area of (500n/h) square feet. Thus the modified shelter will accommodate (500n/10h) persons, which is an increase of

$$\frac{50n}{h} - n = \frac{n(50-h)}{h} \qquad (9)$$

additional space per modified shelter.

D. Selection of Shelters to be Modified

There are several considerations which must be made in selecting shelters for modification. For example, one may wish to modify shelters in those geographical areas in which adequate shelter space is lacking; the selection of the individual shelters to be modified in this case must be based on the geographical distribution of population and shelters within given areas. Another consideration may be the amount of money available for artificial ventilation. It is possible to select shelters for modification so that the maximum number of additional shelter spaces will be provided under specified budgetary limitations; even if other considerations are used in selection of shelters for improvement, these limitations may be used as a base for comparative purposes. Also, one may divide a given area-- such as a city--into smaller areas and allocate different budgets to each of the smaller areas. These different budgets may reflect the need for different amounts of increased spaces in the smaller areas. Then, within each smaller area, one may only want to consider the modification of those shelters which will maximize the increase in shelter spaces for a given total cost. This is the approach taken here.

E. Cost of Modification

Let $C(n)$ denote the cost of modifying a shelter of size n. As n is proportional to the volume of shelter, this would be an adequate independent variable for describing the cost function. In particular a linear cost function of the form

$$C(n) = C_1 + C_2 n \tag{10}$$

where C_1 is the fixed cost and C_2 is the variable cost of modifying a shelter will be used in the illustrative example given below.

The unit cost of an increased space is found by dividing the cost function C(n) by the number of increased spaces given in Equation (9); the unit cost is

$$\frac{h}{50-h}\left[\frac{C_1}{n} + C_2\right] . \tag{11}$$

If we assume that all volume restricted shelters have ceilings of constant height; then the unit cost of an additional space is smallest when the largest shelters are modified. Thus, a limited budget may be most wisely spent by modifying only the largest shelters. Under this strategy, let n_o denote the smallest size shelter modified; all shelters of size n_o or larger are to be modified.

The total cost of modifying the shelters is

$$C_T = M_v \int_{n_o}^{\infty} C(n) f(n|\lambda_v) dn \tag{12}$$

which, upon using the linear cost model, Equation (10), and the functional form of $f(n|\lambda_v)$ given in Equation (6), becomes:

$$C_T = M_v e^{-\lambda_v (n_o - 50)} [C_1 + C_2 (n_o + \frac{1}{\lambda_v}] . \tag{13}$$

This may be solved for n_o when the total cost is equated to the available budget.

F. Computational Technique

If the heights h of the volume restricted shelters are not constant, then the same technique may be used in a modified form. For simplicity, suppose that the distribution of size and ceiling height of shelters is presented in a two way table, with sizes listed across the top of the table and ceiling heights

listed on the edge of the table; the entry in the body of the table denotes the number of shelters with the indicated size and ceiling height. The unit cost for each additional space, calculated from Equation (11) may be added as a second entry in the body of the table. The cost of modifying all of the shelters with a given size and ceiling height may be added to the table as a third entry.

The optimum selection of shelters for modification will be those shelters with the lowest unit costs of additional spaces; the first group selected is indicated by the cell with the lowest unit cost. The total cost for this group is noted and compared with the allowable budget. If the budget money is in excess of the cost of modifying the group of shelters, the cell with the next smallest unit cost is selected and the total cost for modification of the shelters in the two selected cells is compared with the budget. The process is repeated until all of the budgeted monies are used in modification.

G. Spaces Added

The total number of additional shelter spaces for the case of a constant ceiling height is

$$N = M_v \frac{(50-h)}{h} \int_{n_o}^{\infty} nf(n|\lambda_v)dn \ , \qquad (14)$$

which using the definition of $f(n|\lambda_v)$ given in Equation (6) is

$$N = M_v \frac{(50-h)}{h} e^{-\lambda_v(n_o-50)} \quad n_o + \frac{1}{\lambda_v} \quad . \qquad (15)$$

From the equation of total cost (Equation 13) and from Equation (14) the average unit cost of an additional space is

$$\frac{h}{50-h}\left[\frac{C_1}{n_o + \frac{1}{\lambda_v}} + C_2\right] \quad . \qquad (16)$$

H. Numerical Example

As a partial example of the computational technique for the selection of shelters for modification, consider that the shelters in Census Tract 25, Houston, Texas, are to be modified. The parameters of the shelter size distribution for that tract derived in Section V are:

$$\lambda_v = 0.0111 ,$$
$$\lambda_a = 0.00319 ,$$
$$M_v = 64 .$$

An estimate of average ceiling height may be derived by assuming that the volume restricted shelter sizes--if recalculated on an area basis--would have the same distribution as area restricted shelter sizes, and that ceiling heights are constant in all volume restricted shelters. This leads to the identity

$$500\left(50 + \frac{1}{\lambda_v}\right) = 10h\left(50 + \frac{1}{\lambda_a}\right) , \tag{17}$$

from which the estimate h = 19.3 feet is calculated for the parameter values given above.

Next, assume a fixed modification cost of C_1 = \$1000 per shelter modified and a variable cost of C_2 = \$3 per shelter space (or C_2 = \$3 per 500 $ft.^3$). The minimum shelter size is found by setting the total cost equal to the allowable budget:

$$C_T = 64\, e^{-0.0111(n_o-50)} \left[1000+3\left(n_o + \frac{1}{0.0111}\right)\right]$$
$$= 333(0.98895)^{n_o} (n_o+435) \tag{18}$$

and solving for n_o. The total number of spaces added is found by the substitution of n_o into

$$N = \left(\frac{50-19.3}{19.3}\right)(111)(0.98895)^{n_o}[n_o+90]$$

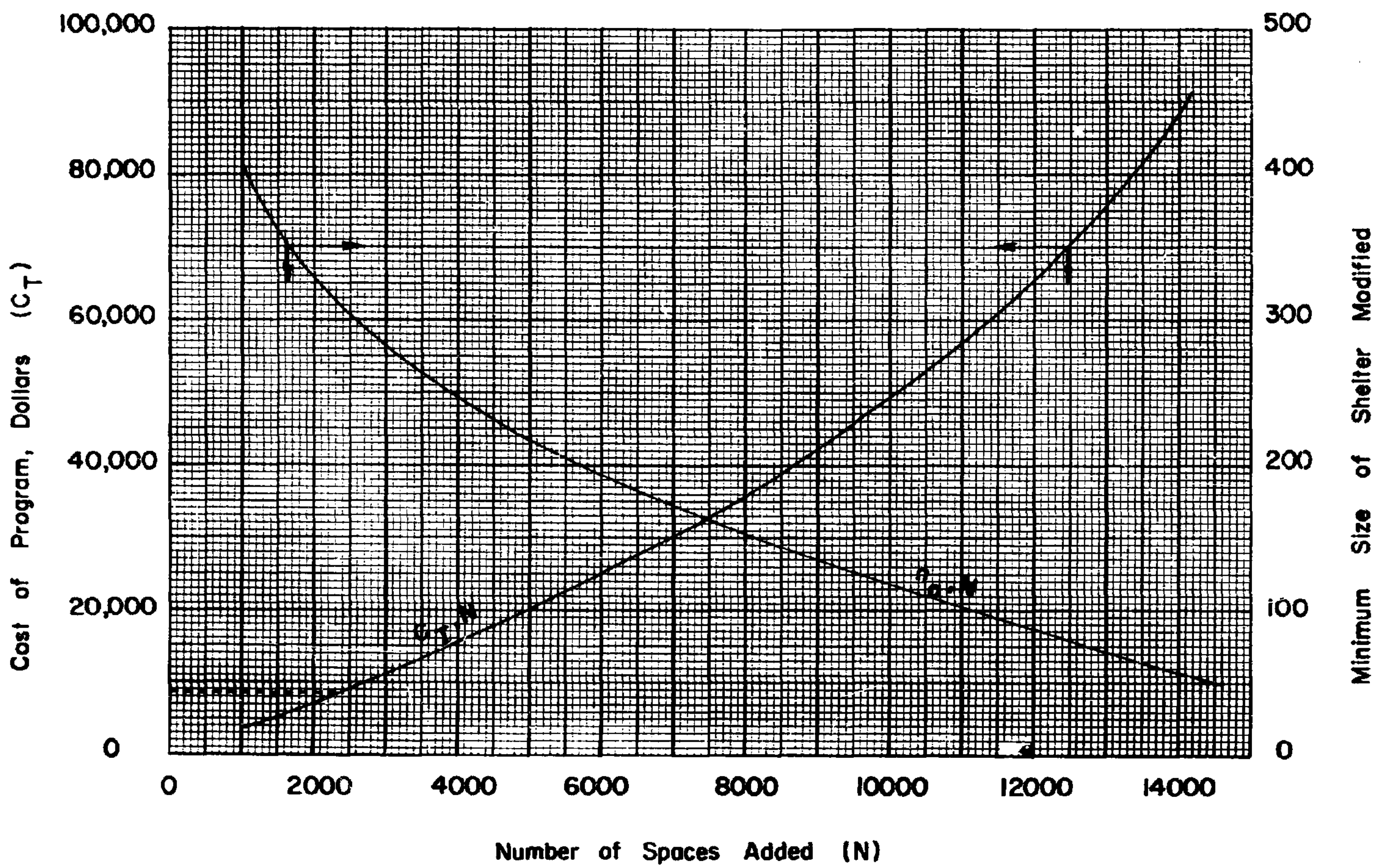
$$= 177[0.98895]^{n_o}\,[n_o + 90]. \tag{19}$$

For a budget of \$8,660, the minimum size of shelter modified is $n_o = 300$, and $N = 2500$ additional spaces will be added.

The structure of the solution is more readily seen in Figure E-6, wherein values of total cost (C_T) and minimum shelter size modified (n_o) are plotted against the number of spaces added (N). The dotted lines indicate the solution given in the above example.

FIGURE E-6

SHELTER MODIFICATION COSTS



VI. APPENDIX E REFERENCES

E-a. Research Triangle Institute. A Fallout Shelter Survey of Four Census Tracts in Houston, Texas, performed by RTI personnel in a test of NFSS procedures and computer PF calculations. Results are available only as an internal memorandum report. The survey was performed under OCD Contract Number SD-96. November, 1961.

E-b. Research Triangle Institute. A Fallout Shelter Survey of Durham, N. C., performed by RTI personnel in a test of NFSS procedures and computer PF calculations. Results are available only as an internal memorandum report. The survey was performed under OCD Contract Number SD-96. October, 1961.

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1	Hughes Aircraft Company Fullerton, California Attn: Mr. R. A. Dibrell

THE RESEARCH TRIANGLE INSTITUTE, Durham, N. C.
OCD Sub-tasks 4521A & 4613A-Final Report R-OU-82/83 Vol.II
Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs. Philip McMullan et al.
13 January 1964 (UNCLASSIFIED) 3 pp.plus 5 appendices.

This volume contains five studies concerned with obtaining, compiling, or analyzing fallout shelter protection data. These studies cover the following subjects: (1) a review of the residential basement data which were obtained from the 1960 U. S. Census of Housing; (2) an examination of electric power availability in the postattack period, with emphasis upon fallout protection in power plants; (3) the preparation of a procedure for extracting summary distributions of overpressure, reference intensity, and fallout arrival time and relating these to numbers of people exposed; these data are to be extracted from the Attack Environment III output tapes of the Jumbo III

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CIVIL DEFENSE SYSTEMS, SYSTEMS EVALUATION, BASEMENT FALLOUT SHELTER (1960 CENSUS OF HOUSING DATA; NATIONAL FALLOUT SHELTER SURVEY DATA), ELECTRICAL POWER SYSTEMS VULNERABILITY, DATA PROCESSING (ATTACK ENVIRONMENT), STATISTICAL DISTRIBUTION FUNCTIONS (FALLOUT SHELTER; POPULATION; OPTIMUM VENTILATION IMPROVEMENT BUDGET).

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